BIM GAME:
A "Serious Game" to Educate Non-experts about Energy-related Design and Living

by

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Abstract:

Climate Change is one defining issue of our time. With the increasingly sophisticated uses of energy, we have to face the problem as energy shortage and global warming. Since almost one-fourth of US energy is consumed by homes, creating high-performance low-energy houses and educating people about energy-related decision making, is perhaps the first and most cost-effective way of addressing energy issue.

Towards this end, I propose a learning tool to educate non-experts about energy-related design and decision-making of their own homes. This tool, BIM Game, is based on BIM (Building Information Modeling) and E-learning game. By integrating BIM and Serious Game together, the new responsive model can change design education from the professionals to all people who care about energy issue and living environment.

Through learning by playing, it is able to create a deep-learning environment and also add emotion to the problem-solving process. It also explores innovative shifts in building industry for consumer participative design and file-to-factory fabrication strategies, change the role of the consumer from the last benefit end-user to the first decision maker. So finally it will take advantage of the inexpensive computation, to raise the public awareness of participative design, energy efficiency, healthy living, and sustainability.

Thesis Supervisor:
Kent Larson
Principal Research Scientist in Architecture

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I have met a lot of nice people along the way since I come to study in the US. It is hard for me to include everyone who makes my life rich and significant here, I will try to mention most of them.

First, I would like to deeply express my gratitude to my advisor, Professor Kent Larson, for his confidence and patience in me, his clarity of thinking, and his constructive criticisms. It is a great experience not only during the thesis semester but throughout the two years of my studies at MIT.

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To my parents and grandparents, for their love.

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Chapter 1

Introduction

1.1 Problem and Challenge: Home Energy Issue

"Architecture is the true symbol of our time."

-- Ludwig Mies van der Rohe

I am writing this thesis on the 4th floor in One Cambrige Building. With a view far out of the window is a development of contemporary housing. These projects are built in the 40s, when the typology of residential architecture and concept of living has undergone radical transformation due to the Modern Movement. However, 70 years later, when *Life* published plans for a neo-traditional shingle-style residence designed by Robert A.M. Stern, it described the project as "a house for all America."[1] Building industry hasn't changed over the century; architects have failed to take up a position in the post-industrial era to address the needs like accommodating responsive, technology, and identity to the built environment.

In the profession, when design focus shifts from singular problem to social awareness, architects start to care more about the greatest challenge facing the world today. Climate Change is one defining issue of our time. With the increasingly sophisticated uses of energy, we increase the strength of building industry, comfort and convenience of home and workplace, speed of transportation, but have to face the problem like global warming, energy shortage, and greenhouse gas emission. The contradiction means that we can not both have an increase demand in our energy use and a habitable planet.

As the population of the globe grows and aspires to a wellness lifestyle, the demand for fossil fuels and raw materials grows beyond our ability to supply them. Climate change is upon us with little controversy any more. The combination means that our housing stock in the US is woefully unprepared to meet the inevitable price increases for energy and the burden on tight budgets that utility costs represent.[2]

We want to reduce the impact on the climate change, but where to start? The answer lies right in our own backyard. In the United States alone, residential units consume 21% of the nation's energy, cause 20% of its greenhouse gas emissions *[Fig 1.1-1]*, and use 5 billion gallons of clean water per day to flush toilets.[3] Buildings have a profound negative impact on our natural environment, human health, and economy.

1 Stephen and Jennifer Allen Petranek, "A House for All America," Life, June 1994, 82-92.
2 David Johnston, Greening America, One House at a Time
3 U.S. Green Building Council (USGBC)

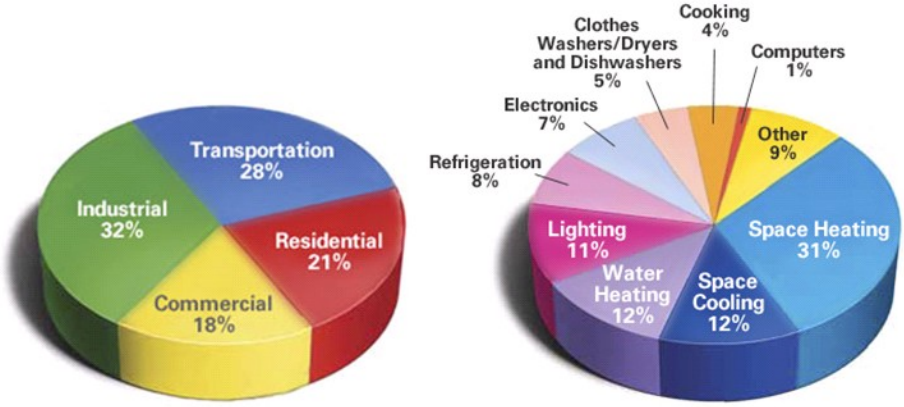


Figure 1.1-1

Percentage of energy consumed by each economic sector in the United States in 2006.

Percentage of energy usage in the U.S. residential sector in 2006.[4]

Since almost one-fourth of US energy is consumed by homes, creating high-performance low-energy homes and educate people about energy-related design and decision making, is perhaps the first and most cost-effective way of addressing energy shortages and global warming.

4 Data from: US Energy Information Administration.

1.2 Strategies for High Performance Low-Energy Homes

1.2.1 Green Design

According to the census bureau, there are about 112 million middle-income, single-family homes in the US, which account for 80% of the contemporary housing market. Unfortunately, less than 1% meets with the sustainable criteria. The majority are not properly designed: poor occupation comfort, reliance on other products to counter the design problem, high energy and operation cost, etc. Contrast to a nation's wasteful unhealthy homes, is people's demand for comfortable low cost homes. Therefore, the marked trend towards carbon neutral or zero emission becomes a vast opportunity for remodeling the building industry.

As the name implies, Green Design is the process of designing and building environmental friendly spaces that use sustainable building materials, eliminate negative impacts on human health and environment, conserve non-renewable resources, increase the energy efficiency of buildings, and promote indoor air quality.

Green design is more important than ever. "As of 2006, 50% of builders are focusing their attention on green building issues, between 40% and 50% of the homes built in 2010 are expected to be green."[5] *[Fig 1.2-1]*

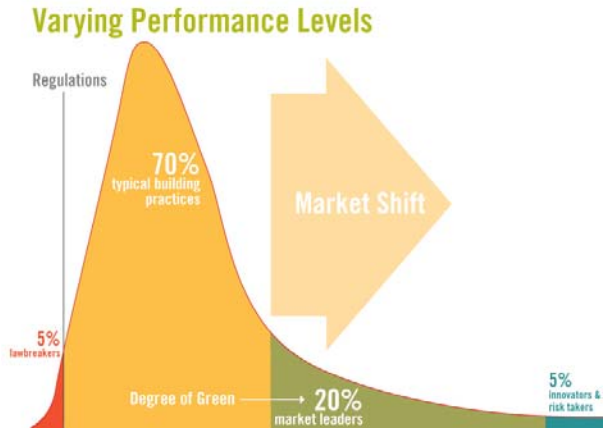


Figure 1.2-1 LEED for Homes: Varying performance levels

The benefits of green design can be summarized as follows:[6]

- The local and global environment benefits from protecting air quality, water quality, and overall biodiversity and ecosystem health *[Fig 1.2-2]*.
- Economic benefits are experienced in building operations, asset value, worker productivity, and the local economy.
- Occupants benefit from health and safety features. This also relates to risk management and economics.
- Community and municipal benefits include: lessened demand for large-scale

5 National Association of Home Builders (NAHB), March, 2007.
6 U.S. EPA Office of Air and Radiation, 1989, Report to Congress on Indoor Air Quality, Volume II: Assessment and Control of Indoor Air Pollution.

infrastructure such as landfills, water supply, and their related development and operational costs; and decreased transportation development and maintenance burden (roads) and increased economic performance of mass transit systems.

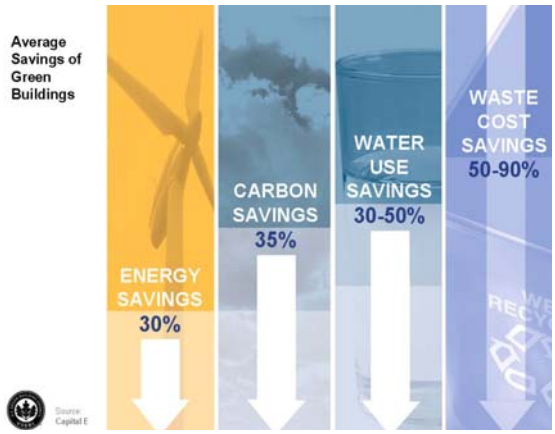


Figure 1.2-2 Average savings of green buildings[7]

To determining how "green" a building is, LEED is the U.S. Green Building Council's Leadership in Energy and Environmental Design building rating program. The LEED Green Building Rating System™ is the nationally accepted benchmark for the design, construction, and operation of high performance green buildings.

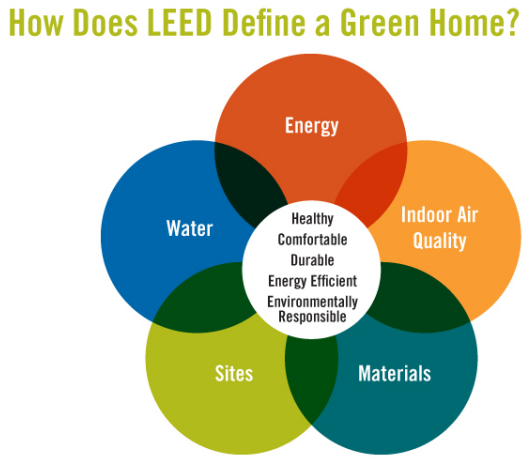


Figure 1.2-3 LEED for Homes: Green home[8]

LEED promotes a whole-building approach to sustainability by recognizing performance in six key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, indoor environmental quality, and Innovation and design process *[Fig 1.2-3]*. LEED-certified buildings are leading the transformation of the built environment, built as designed and perform as expected, have lower operating costs and increased asset value, and are healthy and comfortable for their occupants.[9]

7 U.S. Green Building Council (USGBC)
8 http://www.usgbc.org/DisplayPage.aspx?CMSPageID=147
9 Jeff Ashcroft, LEED Certification for Your Logistics Facilities

LEED Case Study1:

Figure 1.2-4 Carsten Crossings Oakgrove Mode in Rocklinl, California[10]

This 4-bedroom home project with 2,543 square feet is certified with LEED CERTIFIED under the LEED® Green Building Rating System. With careful use of materials, about 75% minimum of all concrete, roofing, drywall and wood construction waste is diverted from landfill. Indoor environmental air quality is boosted by the use of a dedicated mechanical ventilation system for fresh air, and both the mechanical ventilation and HVAC systems underwent third-party verification. The homes also include SunTile™ photovoltaic roof tiles by PowerLight to provide supplemental electricity. The onsite solar power source can reduce electricity bills by as much as 70%. Therefore, this design turns out to have $1,400 yearly savings on utilities.

LEED Case Study2:

Figure 1.2-5 Morrisania homes in bronx, new york[11]

This 28-building, 76-unit mix of two- and three-family homes gets LEED SILVER from its smart selection of building materials, fixtures and appliances. “This successful development proves that we can increase the number of affordable homes, and also protects the environment and increases energy efficiency.”[12] Equipped with 100% appliances with ENERGY STAR rating like dual-flush toilets, 2-gallon-per-minute shower heads and 1.5-gallon-per-minute sink faucets, Morrisania Homes dramatically cut back on the homes’ water use. The lack of fireplaces and garages, along with continuous background ventilation, keep the air healthy. The builders made use of recycled concrete and masonry and bought locally manufactured materials when possible to reduce the carbon emissions from transporting them.

10 www.usgbc.org
11 www.usgbc.org
12 New York Gov. Eliot Spitzer

1.2.2 Green Living

"We don't inherit the Earth from our parents; we borrow it from our children."

-- Chief Seattle

Masdar City is the first and most ambitious sustainable city in the world, and is notable for its zero-carbon, zero-waste, car-free feature. Unfortunately, most of the citizens are not aware of the sustainability, city designers have to figure out more strategies to educate the citizens about green living. *[Lecture notes of MIT class, 4.292 Responsive Cities]*

Figure 1.2-6 Masdar City, Abu Dhabi[13]

Architectural design is to define a space, meanwhile it is also the activities of people and events in the space give the meaning to the building. Today's consumers require high benefit building products, good indoor air quality, and low energy bills. Green building professionals are already trained to deliver green homes. But when talks about living, people still stick to what they have did before. Green living is to affect people's energy-related behavior, with which a few simple lifestyle adjustments can lead people to live healthier and wealthier.

To me, Green Living means to leave a gentle carbon "footprint" on the earth. A Carbon Footprint is the measurement of CO^2 emitted as part of individual's daily life activities. When the calculation is known, individuals can offset the environmental impact of CO^2 emissions from their behavior by deploying a strategy. As individuals, Most of us have already tried to recycle paper and use a reusable mug instead of disposable paper cups. This kind of effects can be noticeable, or at least in bills. But still, we consume energy unconsciously in many other ways all day long. We heat space to keep warm, we turn on light whenever we need it or not, we have hot water, and we use energy to run all the appliances and electronics. Basically, most of the things we behave consume energy contribute to the problem: 21% of the nation's energy, and 20% of its greenhouse gas emissions.

And to make matters worse, on average Americans spend about 90 percent or more of their time indoors.[14] According to USEPA "Indoor Air Quality" 2003, Indoor air has 10-100X higher

13 http://en.wikipedia.org/wiki/Masdar_City

14 Danielle Addai, Americans Spend 90 Percent of Time Indoors - Exposed To Indoor Allergens.

pollutants than outdoor air. 50% of all illnesses are either caused by polluted indoor air.[15] Unhealthy living ways may cause respiratory ailments, allergies, asthma, which results to lower productivity, higher insurance and medical costs *[Fig 1.2-7]*. More than 17 million Americans suffer from asthma, and 4.8 million of them are children. Ten million school days are missed by children each year because of asthma, which is exacerbated by poor IAQ.[16] Therefore, lead a green lifestyle can enhance occupant health and save money on energy and environment at the same time.

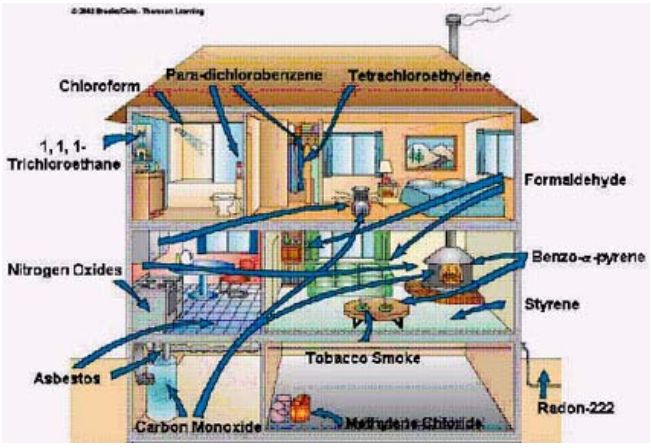


Figure 1.2-7 Indoor Air Pollution/Sick Building Syndrome[17]

So rather than build smart homes, we have to be smart people. Energy trade-off and decision-making permeates our daily life. We can do as all the experts suggest, like print double-sided document and use email, turn the appliances off when not using it, don't throw stuff that can be recycled or reused *[Fig 1.2-8]*, set the temperature lowest in winter and highest in summer, replace light bulbs with compact fluorescent bulbs, and drive less. If we take small actions, the nation as a whole can reduce impact on the environment greatly. For example, if every US family replaces one conventional bulb by one with ENERGY STAR@ label, the energy we save could light up 7 million homes, the BIG number is we reduce equivalent gas emissions by 1 million cars for a year, estimated by the EPA.

Figure 1.2-8 Recycling at Kellogg

15 American College of Allergists.
16 Hathaway, Hargreaves, Thompson, and Novitsky, 1992, "A Study Into the Effects of Light on Children of Elementary School Age - A Case of Daylight Robbery," Policy and Planning Branch, Planning and Information Services Division, Alberta Education, Canada.
17 http://ftmnews.wordpress.com/2007/09/02/4/

However, few people know their own impact. Some understand the Climate Change issues but not aware that they are causing it. Most of adults think they will probably not be affected recently and suggest to teach their younger generation. Other people can't see effective changes directly to their actions so they are not motivated to take responsibilities for this long-term survival. And even if they do know the impact, how can they change their behavior? The question remains, there is a big gap between awareness and behavior change.

The key to incorporate Green Living is education. The more we know, the more we can do to make a difference. The more we make changes in current lifestyle, the more we benefit in the future. For different living patterns to unfold and dealing with post-occupancy green living, we should also educate the occupants how to control over space, time, and the use within it. This recent trend might be possible through participating in the education of green concept. The education will prompt people to rethink energy issue, potentially change their attitudes towards conservation, and finally change their routine behaviors.

Also change doesn't happen individually; people don't want to change alone. Educate the community is another effective way. Overwhelming success has come from community-based education, from existing networks as faith, social circles, university, etc. Through intensively promoted among community and the public at large, the attitude towards green living can change for understanding, and beyond it, accepting.

1.2.3 Green Financing

Cost, Lifetime Cost, Value

As those of us who lack money currently, Green Finance is probably the right way during the economy shrunk. The concept of Green Financing is still not widespread. For most of people, the idea of buying products labeled GREEN means over-priced organic food, unaffordable hybrid cars, and expensive remedies. They believe they can not afford it. How practical is it to buy GREEN? When confronted with the largest commodity investment most people ever make during their life, the house, people are even more reluctantly to practice GREEN. However, Green financing is a way to save money and go green at the same time. Although some of the Green products may cost more than their conventional counterpart initially, over the lifetime of home, the potential of saving is significant. Green Financing enables consumer to maximize their return on the investment and lifecycle value.

By the year 2035, approximately 75% of the built environment will be either new or renovated. This transformation over the next 30 years represents a historic opportunity for the architecture and building AND FINANCE community to avoid dangerous climate change.[18]

The money flow of homes can be categorized as follows: initial purchase investment, operation cost, lifecycle cost, and productivity effects.[19] Initial purchase investment comes from the design and construction. Operation cost includes utility cost (electricity, water, and gas use), replacement and maintenance, insurance and tax, etc. Lifecycle cost is cost over the whole lifetime, taking the time as a factor. Productivity effects result in the value saving from post-occupancy productivity.

Usually when people make decisions about homes, initial purchase investment is the driving factor. However, during the cash flow of 30-year occupation, initial building costs account for approximately just 2% of the total, while operations and maintenance costs equal 6%, and personnel costs equal 92% *[Fig 1.2-9]*.

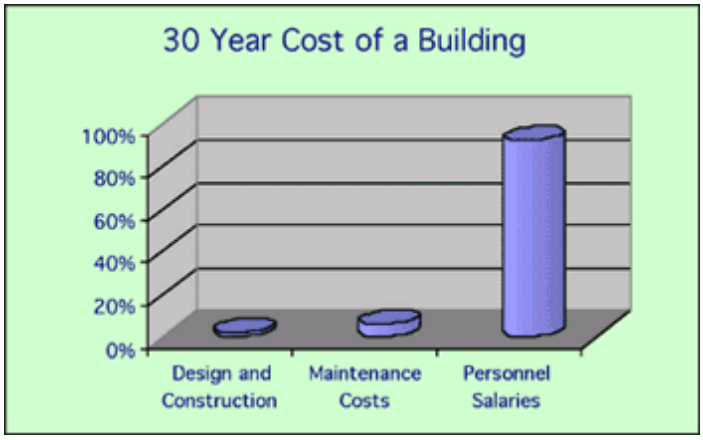


Figure 1.2-9 30 year cost of a building[20]

18 www.2030challenge.com
19 Sieglinde Fuller, Life-Cycle Cost Analysis (LCCA)
20 Sustainable Building Technical Manual

Lifecycle cost is the real long-term cost, compared with the initial design and construction cost. If the consumer reduces the initial investment by installing inefficient systems or poor material as a trade-off, he will pay for it during the occupancy. The improved efficiency can lower utility bills and reduce the operation and maintenance cost such as electricity, water, and gas. For example, below is the comparison of two building materials *[Fig 1.2-10]*. At first glance, Vinyl is much cheaper than Linoleum per square. But during the 40 years, Vinyl has to be replaced 4 times while Linoleum is still in good shape. So an expensive product can be more economical during the long run for its good performance and durability.

Sheet Vinyl	Linoleum
5,000 sq. ft.	5,000 sq. ft.
$1.50/ sq. ft.	$ 5/sq.ft.
Replace every 10 years	Replace every 40 years
Total 40 yr. Cost: $30,000	Total Cost: $25,000

Figure 1.2-10 30 Material Cost & Lifetime Cost[21]

Payback considers the time to recover the initial investment. Looking at ROI (Return on Investment) enables better comparisons between green buildings strategies and components.[22] When considering the benefits of installing independent energy backup systems, the cleanest form is solar photovoltaic installed on the structure. The overall payback period for a solar system can now be as low as 7 years *[Fig 1.2-11]*.

ITEM	Approximate Payback	Approximate ROI
Lighting	6-18 months	20%
HVAC	3-5 years	12%
Photovoltaic	7-10 years (with rebates)	5%

Figure 1.2-11 ROI of Building Components

Here is a graphic image of the value of making design decisions based on long-term cost analysis *[Fig 1.2-12]*. You see that the potential 2% increase in initial capital expenditures for a high performance building are paid for after a few years by the lower operating costs. Over the life of the 20 year bond, however, long-term savings grow at an ever increasing rate.[23]

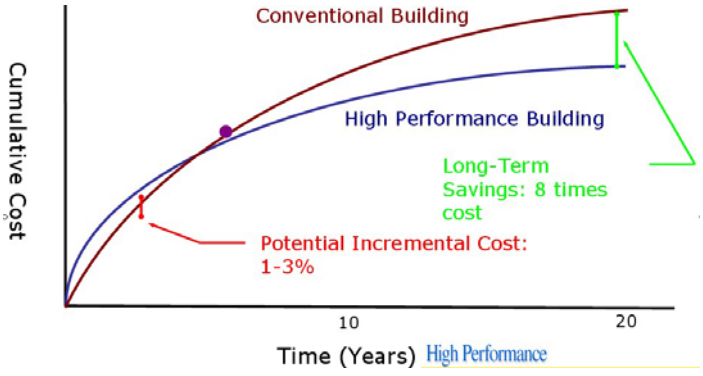


Figure 1.2-12 Incremental cost-benefit model

21 Michelle M. Caron, GREEN AFFORDABLE HOUSING EXAMPLES & POSSIBILITIES

22 The Costs and Financial Benefits of Green Buildings, A Report to California's Sustainable Building Task Force – October 2003

23 Belmont Vision 21 Implementation Committee and Sustainable Belmont, High Performance Green Buildings: An Overview

Besides, life-cycle cost savings far exceed any investment in design and construction phase. From the figure below *[Fig 1.2-13]*, we can see Percentage breakdown of green building financial benefits.

Financial Benefits of Green Buildings (per ft^2)	
Category	**20-year NPV**
Energy Value	$5.79
Emissions Value	$1.18
Water Value	$0.51
Waste Value (construction only) – 1 year	$0.03
Commissioning O7M Value	$8.47
Productivity and Health Value (Certified and Silver)	$36.89
Productivity and Health Value (Gold and Platinum)	$55.33
Less Green Cost Premium	($4.00)
Total 20-year NPV (Certified and Silver)	**$48.87**
Total 20-year NPV (Gold and Platinum)	**$67.31**

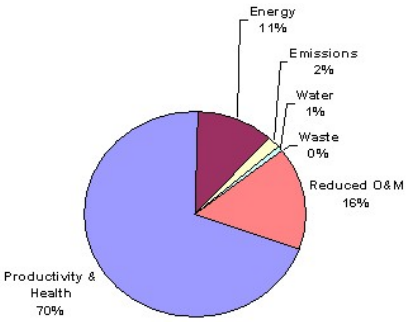


Figure 1.2-13 Percentage breakdown of green building financial benefits[24]

Green is also associated with Value. Green benefits are real; buildings can lead to 25-60% energy savings, and 30-50% water savings.[25] However, value is hard to define, and cost doesn't equal value. Lifecycle value has more profound meaning from building's high performance, improved health and quality of life. It also reduces sick time from allergies, asthma and respiratory illness.[26] Relation exists between IAQ and occupant wellness and productivity. Due to improved day-lighting and comfortable thermal temperature, people's productivity can increase by 20-30%! A 1% increase in productivity (about 5 minutes per day) equals $600-700 per employee per year - a ^1.5% equals about $1,000/yr.[27]
Examples are:

- Adding skylight to retail store increased productivity 40% (Heschong Mahone Gp)
- Conversion energy savings gave payback 4.1 yrs / ROI 24% but benefits from lower absenteeism and productivity payback 69 days / ROI 540% (Penn. Power & Light)
- CABE "Value of Good Design" - hospital eco renovation gave 21% improvement in discharge rates, care quality, speed, satisfaction, less drugs, reduced visits[28]

Green Products, Energy Star

As the commitment to Green living and financing grows, it is necessary for consumers to make informed decisions. Green products don't look different from conventional products, but they perform better. While there are a large number of Green products on the market, there is little information to teach consumers about which to choose.

Recognized by 40% of U.S. households[29], ENERGY STAR@ is the symbol of efficient energy product for homes and buildings. ENERGY STAR@ qualified homes must be at least 30 percent more energy efficient than homes built to the 1993 Model Energy Code, or 15

24 The Costs and Financial Benefits of Green Buildings, A Report to California's Sustainable Building Task Force – October 2003
25 John Metras, P.Eng. SUSTAINABLE BUILDINGS, A New Approach to Building
26 John Metras, P.Eng. SUSTAINABLE BUILDINGS, A New Approach to Building
27 Katz 2003 study
28 Jim Green MSc MRICS CES, "Green Value" Green buildings, growing assets, a new RICS international report
29 Selim Karabulut ICF Consulting, ENERGY STAR® Home Improvement

percent more efficient than state energy codes, whichever is more rigorous. These savings are based on heating, cooling, and hot water energy use and are typically achieved through a combination of building envelope improvements, high performance windows, controlling air infiltration, efficient furnaces, air conditioners and domestic hot water equipment and sealed ducts.[30]

Product Savings[31]

- Refrigerators -- At least 15% more efficient than the minimum federal efficiency standard.
- Clothes Washers -- Compared to a model manufactured before 1994, an ENERGY STAR qualified clothes washer can save up to $110 per year on your utility bills.
- Dishwashers -- Use a minimum of 25% less energy than the federal minimum standard for energy consumption.
- Compact Fluorescent Lights (CFLs) -- Use 2⁄3 less energy than a standard incandescent bulb and last 6-10 times longer.
- Furnaces -- Offer a rating of 90% AFUE or greater, which is about 15% more efficient than the minimum federal efficiency standard.

This is the cost benefit report of water efficiency upgrade *[Fig 1.2-14]*. A minimal investment in the ENERGY STAR@ products can yields life-cycle savings of over ten times the initial investment.[32]

Fixture	Replacement/Fix	Estimated Cost	Water Savings	Payback
Kitchen Aerators	30	$120	$328.50	~4 months
Shower Heads	25	$75	$2190.00	~13 days
Bathroom Aerators	43	$32.35	$376.00	~1 month
Fixing Sink Leaks	4	N/A	~$100	Immediate
TOTAL =		$227.30	$2994.50	~1 ½ months

Figure 1.2-14 Estimated Paybacks on Water Efficiency Upgrades

The EPA Home Improvement team developed 2 initiatives (The envelope and the heating and cooling system) to address the major systems in your home. The major focus of these initiatives were to promote the importance of the overall shell working together to provide comfort and savings or the overall performance of the HVAC system rather than just the efficiency of the box.[33]

30 Moving to Affordable Housing with ENERGY STAR®, www.energystar.gov
31 Moving to Affordable Housing with ENERGY STAR®
32 Lauren Baumann Senior Associate New Ecology, Inc. Achieving Sustainable Rehabilitation
33 Selim Karabulut ICF Consulting, ENERGY STAR® Home Improvement

1.3 Current Model

1.3.1 Contemporary Housing Industry

The single-family housing becomes an eyesore in small towns and devours the outskirts of cities. The average U.S. family spent 25% of its income on transportation in suburban areas[34]. Low density areas dependent on automobiles require more energy cost. *[Fig 1.3-1]*

The vicious cycle is because of the poor planning. Auto transportation and highway expansion accelerate the problem of urban sprawling, while the low density demands great use of automobiles. It is hugely wasteful when it comes to energy. Alternative to this is we have to start more effective planning, emphasize the connection between land use and transportation, and create more compact land uses that is amenable to transportation, walking, and bicycling.

Figure 1.3-1 Highway sprawling, Urban sprawling[35]

When the phrases cohousing, live/work, grand-families housing, SROs are made up, how often do you see them? What constituted the contemporary housing market mostly are housing without being "architectured". In contrast to the homogeneity of contemporary housing industry, family composition and human needs are changing rapidly. Only 1/4 of US households fit the traditional nuclear family, 1/10 fit the "Ozzie and Harriet" model[36], 29% consist of couples without children. Besides, grand-families increase 76 percent since 1970 and 1/5 of the families with children are headed by a single parent.[37] Also when other influencing factors such as evolving computer and communication technology come into our life, it is essential to address all these needs.

Should a house be energy efficient? Can it be more environmental friendly?
Should a house be customized for its occupants?
Is the housing estate the only solution to single-family housing?
These are the questions I am going to find out.

34 www.lgc.org
35 http://dailysprawl.blogspot.com/2007/08/weekly-sprawl-sighting.html, http://www.livablestreets.com/streetswiki/costs-of-sprawl
36 Working father, homemaking mother, children younger than 18.
37 Choice in Housing, Promoting Diversity, by Sherry B. Ahzrentzen.

1.3.2 What Other Industries are Doing

Since Le Corbusier's manifesto "House is a machine for living in", machines have taken the place of human being in many ways. In Negroponte's book Soft Architecture Machines, the key idea is "computer-aided participatory design". Negroponte's general theory is "each individual can be his own architect". He argues that "the persons who are to inhabit a house need to participate in its design, computer graphical interfaces make such participation possible".

Now in the post-industrial time, every industry goes to modular. Modular design is a word from system engineering, which is an approach that subdivides a system into modules and then used in other different systems. Since Industry agrees on interface standards for how things connect (not on what gets connected), just as the PC industry found agreement on network protocols and the USB port *[Fig 1.3-2]*.[38]

Figure 1.3-2 USB port

Mass customization is the transition from mass production to produce customer specified products or services. It is the central design strategy for the car manufacturing industry, computer, furniture, and especially in clothes industry for everyone's unique in size and shape. "Mass customization is quickly evolving from an art into a science", said Pete Butenhoff, president of the Textile/Clothing Technology Corp. Recently, a type of "online factory" with e-service appears, in which people can use very easy software to design their own product. For example, EMachineShop.com is a site which customer can download software, design product and send back, and the product will be manufactured in a few days *[Fig 1.3-3]*.

Figure 1.3-3 EMachineShop.com

38 Kent Larson, The home of the future.

Advances in digital technology also influence mass customization to the building industry. It meets customer's needs with mass production efficiency. Based on file to factory manufacturing technology, building component suppliers have delivered a high degree of home automation. All components should be interoperable with each other in the "Demand Supply chain", from building components, to system, to technology. Controlled and precise fabrication of integrated components will more easily allow new materials such as advanced polymers, composites, and special-purpose metals to find their way into the home. It will also permit the low-cost embedding of delicate electronics and devices into the fabric of the environment.[39]

In the category of mass customization, "collaborative customization" is more suitable to the home industry. Different from the "DIY" mode, this is done when customer and designer engage in a dialogue to co-design. Now since computation become ubiquitous in our daily life, we have more opportunities to approach design. In order to have a decision-making role in the generation of home designs, individuals will gain more control over the configuration and performance of their home.

39 Kent Larson, The home of the future.

1.3.3 Current Tools for Consumer Participation

Since most of the time, consumers have little experience or have difficulty navigating through the complex design process, and architect also have problems to teach consumer about sustainability, certain non-expert learning toolkit will become a media for consumer participation.

Current tools:

1. Usually questionnaire is very easy for non-expert to understand, but the procedure is not educational, and the consumer is not participative *[Fig 1.3-4]*.

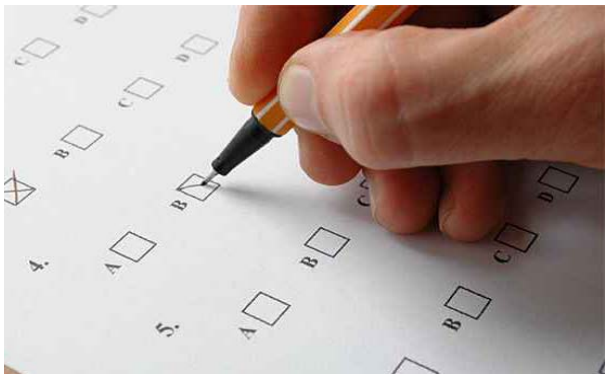


Figure 1.3-4 Questionnaire

2. 3DMax modeling and visualization are tool-orientated, they provide qualitative realistic rendering, but unable to interpret user needs and help users to make informed decisions *[Fig 1.3-5]*.

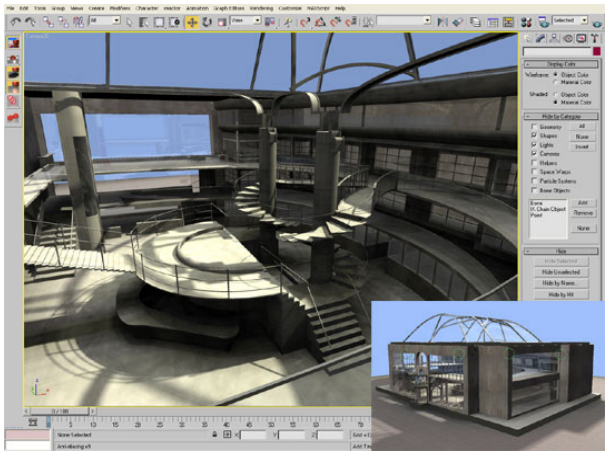


Figure 1.3-5 Modeling

3. Ecotect is a software that simulates the energy use and performance of a building. The interface is designed for the very experts and it doesn't give optimization solutions *[Fig 1.3-6]*.

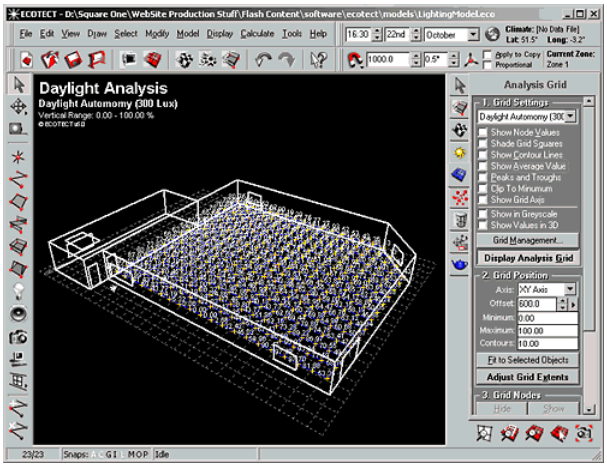


Figure 1.3-6 Energy analysis

4. Web-based static product description is easy to understand, but impossible to modify parametrically and also can't input and output interactively *[Fig 1.3-7]*.

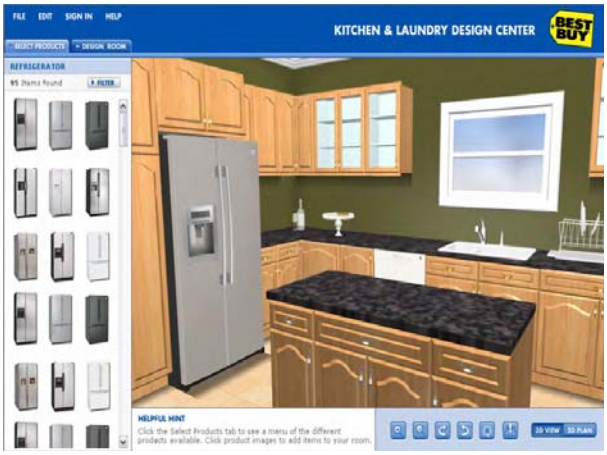


Figure 1.3-7 Web-based configuration

5. Autodesk Project Dragonfly is more of a drag and drop application that focuses on 2d and 3d architectural design. It can be interpreted by non-expert very easily *[Fig 1.3-8]*.

Figure 1.3-8 Design Configuration

1.4 New Model: Integrated Design System

While professional architects always targets at form and style, consumers are devoted more to building performance. For a long time, green seems only serve as an alternative to the mainstream housing development model. However, since the conventional market has shrunk, the same economic driving force towards more reliable, low risk housing investment, demands a new model with precisely energy use and lifetime cost. We need a design strategy to achieve this.

The proposed new model is a collaborative lifetime building design approach. The essential effort is to make it integral, not an "after green" approach. The integrated design will combine green design, green living, and green financing, taking into account in every aspect of the building life cycle. This means consumer will work directly with architects to decide the design solutions and learn how to achieve the above three objectives by designing durable, comfortable, affordable homes.

In the integrated design approach, design a low energy home means to design a green system, and built as designed and performs as expected.
The goal requires many factors taken into account:

- Site planning
- Design
- Construction (Material, Landfill)
- Operation and maintenance (Indoor air quality, Energy, Water, Lifetime cost)

ALL of these factors will affect the design decisions and performance.

The problem of conventional design process, is linear, developer-centric, a series of hand-off in the info transaction, and "Green" added very late in the design cycle when most of the building features can't be changed *[Fig 1.4-1]*. Besides, the energy analysis is not integrated in the usual workflow. Simulations run after the initial design and changes are made in the next design iteration, whose result perhaps is not the optimal solution. The whole process doesn't involve planning, so it doesn't take into account the consumer factor.

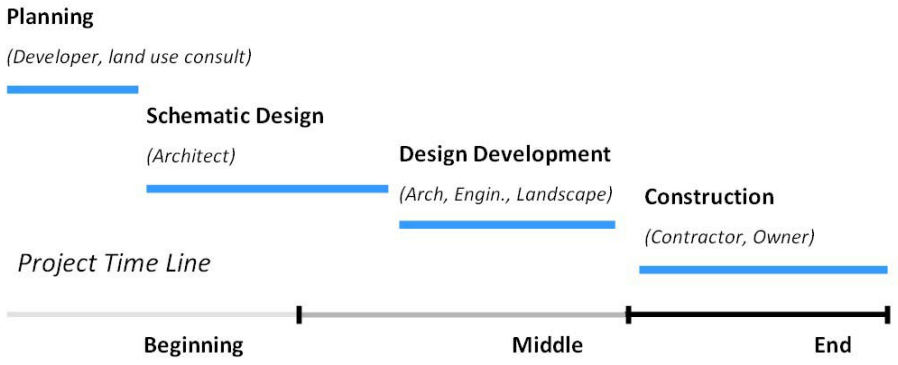


Figure 1.4-1 Conventional Design Process

In contrast to the traditional, developer-centric process where designers and consumers have

minimal involvement and communication, the proposed new collaborative integrated design approach is based on BIM (Building Information Modeling), the learning tool is plug-in into the schematic design process *[Fig 1.4-2]*. It assures the consumers make early decisions about performance and lifetime cost, get more environmentally friendly homes, and also learn about post-occupancy energy-relate behavior change.

Since architectural design is a complex process, the diagram below is just a simple abstraction. Also we have to admit it certainly will be a design iteration process.

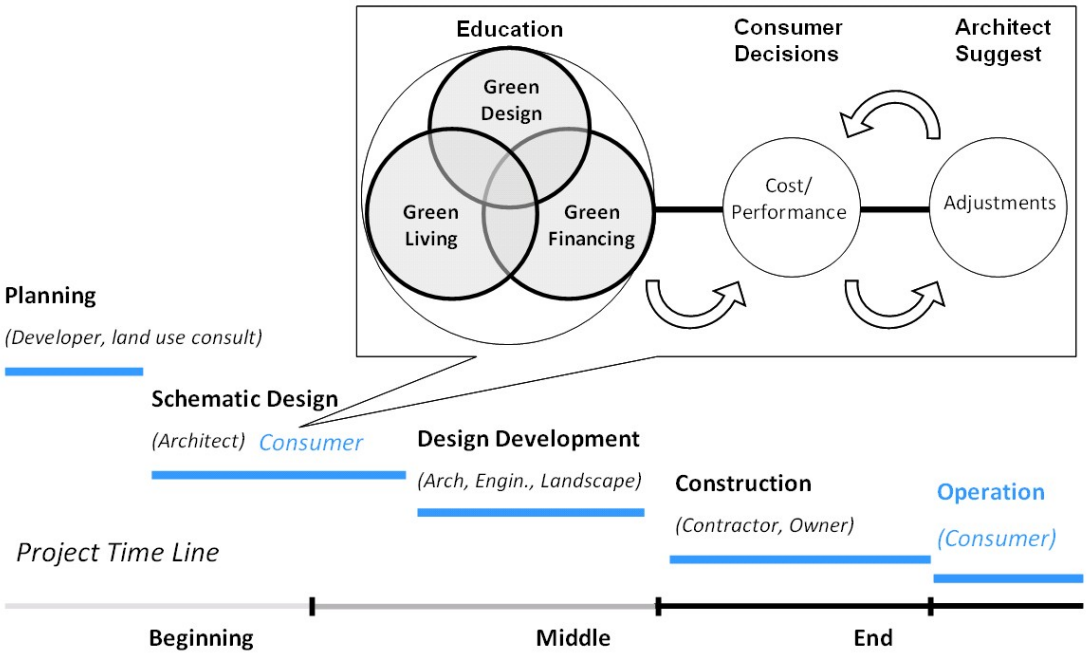


Figure 1.4-2 Proposed Design Process

The non-expert oriented learning tool will help consumers to behave actively in the design process, recognize their own needs, find the particular solutions, negotiate his design with architects and make informed decisions. To allow non-experts to use this learning tool, simple interaction is most important. An easy interface will allow the user to reflect on their real demand in advance, and offers the free choices of space elements and planning for future expansion and growth.

Chapter 2

Learning through Playing

"Games represent a new lively art, one as appropriate for the digital age as those earlier media were for the machine age. They open up new aesthetic experiences and transform the computer screen into a realm of experimentation and innovation that is broadly accessible."

--Henry Jenkins

2.1 Game & E-learning

To keep up with our time, there are many ways for recreation. Games might be the first and most popular topic to come up when talking about our childhood memory. Some even say it is in this century that cinema will come to an end: the entertainment media is changing rapidly with new technology *[Fig 2.1-1]*. Ben Sawyer, president from DigitalMill also said, "Games are the fastest-growing entertainment business and represent billions in worldwide revenue."

Baby Boomers	Generation	Net Gen
TV generation	Video games	Web
Typewriters	PCs	Mobile devices
Telephone	Commands	Online community
Memo	E-mail	IM, blogs
Party lines	Mailing lists	Virtual communities
LPs	Cassettes	CDs, MP3s

Figure 2.1-1 Alan Kay, Product of the environment

As a form of media, game is not well treated by other mainstream media. However, a comparison of game with music and movie show that game industry is much larger than most people think. US economy was under stress last year, but game industry sales have major growth *[Fig 2.1-2]*.

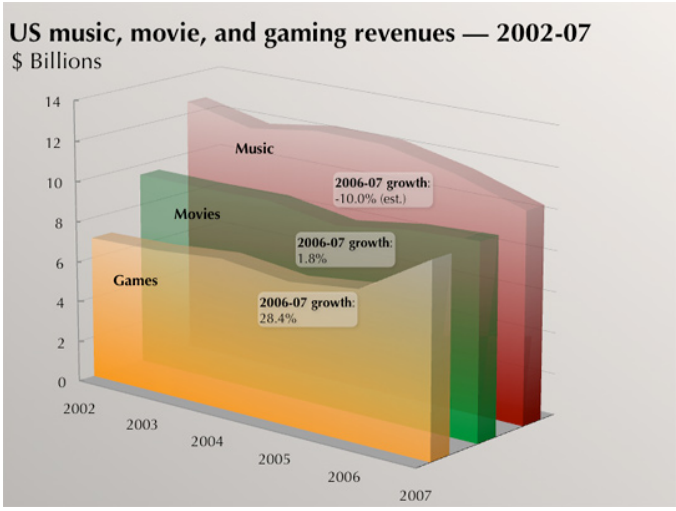


Figure 2.1-2 US music, movie, and gaming revenues – 2002-07[40]

There is no doubt that people put more time from other media to games. Recently, video and computer games are growing fast out of their traditional form for the high quality, interactive and realistic graphics. Figures suggest that nearly 70% of children play computer games every week, and mobile games play is increasingly common, with 68% of children playing games on their phone every week.[41] By age 21, the average person in the US will have spent:[42]

- 10,000 hours video games
- 20,000 hours TV
- 10,000 hours cell phone
- 200,000 emails
- Under 5,000 hours reading

A survey conducted by Henry Jenkins and Kurt Squire, demonstrates game's potential and popularity that "88 percent of them had played games before they were 10 years old, and more than 75 percent of them were still playing games at least once a month.8 Sixty percent of MIT students spend an hour or more a week playing computer games. By comparison, only 33 percent spend an hour or more a week watching television, and only 43 percent spend an hour or more per week reading anything other than assigned textbooks."[43]

As games become increasingly popular, understanding their potential for learning becomes more essential. In Chris Dede's book "Planning for Neomillenial Learning Styles", he points out that "Fluency in multiple media and in simulation-based virtual settings, communal learning involving diverse, tacit, situated experience, and with knowledge distributed across a community and a context as well as within an individual, a balance among experiential learning, guided mentoring, and collective reflection; expression through nonlinear, associational webs of representations; co-design of learning experiences personalized to individual needs and preferences." He proposes game as a new media for learning, and teaching also need to reflect Neomillenial learning styles.

Thomas Malone has identified games into three main ways to motivate players: fantasy, challenge and curiosity. When a player is focused in a game, he is more likely to solve complex problem and interpret new knowledge. As Prensky's interpretation, "the challenges presented and your ability to solve them is almost perfectly matched, and you often accomplish things that you didn't think you could, along with a great deal of pleasure."[44] Play might enable a learner to solve problems that they might otherwise not be able to address in a different state of mind.[45]

40 Anita Frazier, NPD Group; ESA; MPAA; BoxOfficeMojo.com; RIAA; IFPI
41 Magdalena Claro, Video games and education.
42 Marc Prensky. 2003. Digital Game Based Learning.
43 Kurt Squire and Henry Jenkins, "Harnessing the Power of Games in Education." Insight. Vol. 3, 2003.
44 Marc Prensky, Digital-Game Based Learning. (New York: McGraw-Hill, 2004).
45 Keri Facer, "Computer Games and Learning: Why Do We Think it's Worth Talking about Computer Games and Learning in the Same Breath?" Nesta FutureLab website.
http://www.nestafuturelab.org/research/discuss/02discuss0l .htm.

Learners are changing their expectations about education materials, how to educate is becoming more difficult and more important. Edutainment is a form of entertainment designed to educate as well as to amuse. It typically seeks to instruct or socialize its audience by embedding lessons in some familiar form of entertainment: television programs, computer and video games, films, music, websites, multimedia software, etc.[46] E-Learning is a type of Technology supported education/learning (TSL) where the medium of instruction is computer technology, particularly involving digital technologies *[Fig 2.1-3]*.[47] Current research suggests Net Generation students are more likely to engage in online games than to interact with other students or the instructor when in face-to-face learning environments.[48]

Figure 2.1-3 Teaching with Games trial at Bedminster Down School using RollerCoaster Tycoon[49]

We all agree that we play in a fantastic environment, but learn with a limited strict method by choosing major, staying in classroom, working in groups. So how to bridge the gap between learning motivation and conventional academic disciplines, transform people from passive recipients into active learner? Game is a way to provide major benefits for contextualized Learning, which is both motivating and engaging.

Benefits of eLearning versus traditional classroom settings:[50]

- Reducing environmental impact: eLearning allows people to avoid travel, thus reducing the overall carbon output. The fact that it takes place in a virtual environment also allows some reduction of paper usage.
- Quality education, made affordable: Recognized experts have the opportunity of making information available internationally, to anyone interested at minimum costs. This can drastically reduce the costs of higher education, making it much more affordable and accessible to the masses. An internet connection, a computer, and a projector would allow an entire classroom in a third world university to benefit from the knowledge of an opinion leader.
- Convenience and flexibility to learners: in many contexts, eLearning is self-paced and the learning sessions are available 24x7. Learners are not bound to a specific day/time to physically attend classes. They can also pause learning sessions at their convenience.

46 Children's educational computer games, from Wikipedia, the free encyclopedia.
47 Electronic learning, From Wikipedia, the free encyclopedia.
48 J. Foreman, "Next-Generation Educational Technology versus the Lecture," *EDUCAUSE Review*, Vol. 38, No. 4, July/August 2003.
49 Teaching with games, Richard Sandford, Mary Ulicsak, Keri Facer and Tim Rudd
50 Electronic learning, From Wikipedia, the free encyclopedia.

2.1.1 Serious Game

A serious game is a term used to refer to software or hardware application developed with game technology and game design principles for a primary purpose other than pure entertainment. The Serious adjective is generally appended to refer to products used by industries like defense, education, scientific exploration, health care, emergency management, city planning, engineering, religion, and politics.[51]

Mike Zyda gave games and serious game a clear definition that game is “a physical or mental contest, played according to specific rules, with the goal of amusing or rewarding the participant.”, while serious game is “a mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives.”[52] So traditional games are mainly for entertain, serious game can influence players in a meaningful way.

During 30 more years of evolution, computer game today means software with media conventions. To get a snapshot of current serious game industry, here is the taxonomy from DigitalMill *[Fig 2.1-4]*.

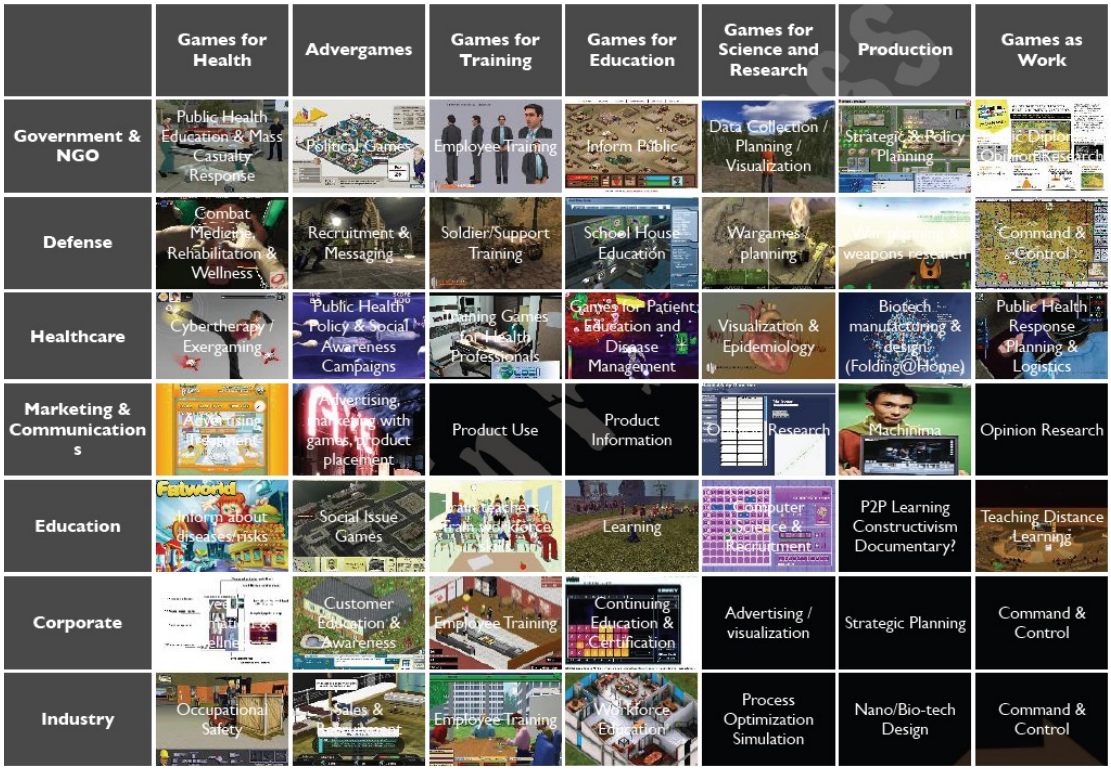


Figure 2.1-4 Taxonomy of Serious Games[53]

For example, this game below is used by government & NGO for scientific research *[Fig 2.1-5]*. Game-based research use gameplay to create more accessible forms of visualization,

51 Serious game, from Wikipedia, the free encyclopedia.
52 Mike Zyda , From visual simulation to virtual reality to games.
53 Ben Sawyer & Peter Smith, serious-games-taxonomy-2008_web

enhance motivation to learn and engage in education, and accomplish tasks like data collection after the game.

	For Science and Research
Government & NGO	

Figure 2.1-5 Game for Government & NGO[54]

After researchers found computer games are extremely valuable for scientific research, they also found that games can be part of the school curriculum. With the increasing interest in pleasurable learning, games provide skills training like: collaboration, decision making, probability, strategic thinking, planning, communication, etc.

Serious games not only provide the player with education and training, but also entertain experience. The matter of serious game is entertainment should overpass education, but that doesn't mean they don't need to be fun. Games are usually highly stylized, with the technologies for creating fidelity visualization, user-friendly interface, simple rules of play, and simulated story and avatars. The key to design games in this way is to reduce the delta between playing and the result, so as to provide an immersive playing environment. That is also the difference between interactive play and passive exposure, when talk about learning. No matter how good the teaching is, if no one wants to play the game is failed.

Simulation and adventure games can be used as class-based education material as well. They engage people to work more actively and learn better. Since players can create society or imagine social relationships, they can reflect on the intricacies of real world and also develop their strategic thinking and planning skills. "Sim City" probably is the most popular one in the class setting.

54 Ben Sawyer & Peter Smith, serious-games-taxonomy-2008_web

2.1.2 Case Study of "Sim City 3000TM"

Figure 2.1-6 Sim City 3000 TM[55]

SimCity 3000TM is borrowing ideas from urban planners, following the scientific methods *[Fig 2.1-6]*. It is a real-time city-building simulation game. It encourage players to "mark land as being zoned as commercial, industrial, or residential, add buildings, change the tax rate, build a power grid, and build transportation systems and many other actions, in order to enhance the city."[56]

Players start from an empty plot and use different tools to build and design a city. The information window on the side gives population, pollution, budget and industry growth rate. If players make bad decisions about zoning and planning, "Sim" will acclaim on the city newspaper.

It offers an intriguing space of possibility for the user, providing a responsive virtual environment equipped with tools for users to build and administer an entire virtual city.
Building Cities: (Problem Solving)

- Zoning areas as Residential, Commercial or Industrial.
- Building roads, rail systems, power and water facilities.
- Taxing and appropriating funds.
- Building police stations, fire stations, and hospitals.
- Including educational institutions and libraries.
- Adding zoos, parks and recreational areas.
- Building marinas, airports, and seaports[57]

Often, such commercial strategy games would return to the professional world, as was the case with Hidden Agenda employed in the training of diplomats and CIA agents (Herz 1997: 222) or SimCity extensively used at the 1994 Mayors Conference in Portland (Herz 1997: 221).[58]

55 http://www.renslt.org/gamez/2335859-simcity-3000-a.html
56 SimCity, from Wikipedia, the free encyclopedia.
57 Mizuko Ito, Uses and Subversions of SimCity 2000TM
58 Kacper Pobłocki, Becoming-state:The bio-cultural imperialism of Sid Meier.s Civilization.

2.2 Play & Design & Learn

2.2.1 Design as a Game

In his book "The sciences of the artificial", Herbert Simon defined design as "the sciences of the artificial and the architecture of complexity". Simon claims that "Everyone designs who devise courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state."

According to Habraken, "First: there are always many designers. The artifact to be made is designed in a process of cooperation and negotiation among many factors. The participation designers have different expertise and their responsibilities in the larger design task can be distributed in many ways. Second: the artifact changes continuously. Human settlements are never finished and we keep designing them. Though each designer can finish his individual task, urban environments and also individual buildings continue to be designed upon throughout their lifetime."[59]

Design is an act of seeing, thinking and making. As Simon indicates, to design a complicated artifact, one powerful technique is to discover viable ways of decomposing it into semi-independent components corresponding to its many functional parts.[60] The design of each component can then be carried out with some degree of independence of the design of others, since each will affect the others largely through its function and independently of the details of the mechanisms that accomplish the function.[61]

Greg Costikyan, in his lecture Design for Serious Games, said "Games are systems, mutable and exploratory, demonstrate the complexity of the situation, show the constraints of different actors, inculcate rational problem-solving". He also argues, this system allow players to think about games as systems and designed spaces rather than simply moment-by-moment playable environments.

In real life experience, we should pay great attention to the function and building code, to make the building really "work". This nearly decomposable system can also be used in architectural design. Buildings are designed by many professional architects with quite different aesthetic sense and background. But games are usually defined as a "trial and error" process to gain certain property or overcome obstacle with much degree of freedom, which are not really related to the real life function. The key of design as a game is, through a game we can learn the design process and achieve the similar design goal.

59 Concept Design Games, Harbraken & Gross, 1987.
60 The Sciences of the Artificial, Herbert Simon, 3rd edition, 1996.
61 The Sciences of the Artificial, Herbert Simon, 3rd edition, 1996.

2.2.2 Game as a Design Tool

It is our century to see design as a personal endeavor. The advances in game technology start to explore how to use games to support design.

Design is a rule-based game. When design involves many parameters, we see the similarity between board games *[Fig 2.2-1]*:

- Layout: the player enters the game space and interacts, while design is taken place in a site and sort of defined context, setting a condition in which designer has to manipulate.
- Goals: player use strategies to achieve certain demands in order to win the game, designer make configuration to meet design concept. Constraints and rules imposed on the players establish a game.[62] In these ways our games resemble real-life design situations.
- Rules: the rules provide player the basic features, function and principles to limit their interaction/move in the game space, while in contrast to real-life experience, designer take into account all the relationship of components, and make negotiable arrangements about form, function, etc.
- Configuration: In the game, how the player move/fit the pieces on a board is the core of the game. As when designing, designer organize and transform complex configurations, while making decisions and arrangements as to how to go about their work.

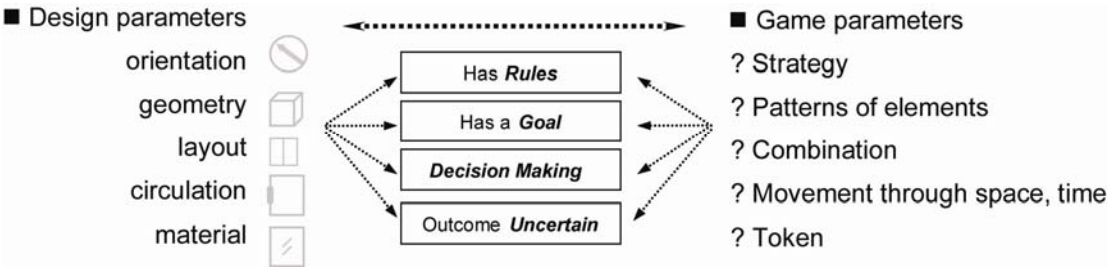


Figure 2.2-1 Design parameters & Game parameters

Game could be a design tool for all level of players with interactive input or output. According to Herbert Simon, "the proper study of mankind is the science of design, not only as the professional component of a technical education, but as a core discipline for every liberally educated person".[63] Design is a science, "Solving a problem simply means representing it so as to make the solution transparent"[64]

Now we see the design paradigm shifts from problem solving towards collaborative design. A major requirement of such shift deals with some aspects of the learning and collaboration problem. Game is a powerful form of learning tool to pass on the professional knowledge and relationship that define the design.

62 Concept Design Games, Harbraken & Gross, 1987.
63 The Sciences of the Artificial, Herbert Simon, 3rd edition, 1996.
64 The Sciences of the Artificial, Herbert Simon, 3rd edition, 1996.

2.2.3 Learning through Playing

"I learned more history in one day than the last 6 months "

Student, 15 years

We love playing games. Playing is fun, competition and collaboration is exciting, failure is acceptable, after all it is a game. On the other hand, we also have to dive into, memorize and analyze, make decisions, and reflect on their strategies. Does that sound familiar like learning?

Learning involves decision making, problem solving, and critical thinking. Playing can provoke learning through competition/ cooperation, role-playing, imagination, exploration, experimentation, and challenge creativity. The belief of "learning through playing" is based on these activities.

Remember when we are young, we bring out skills out of playing. Playing allows us to pay full attention, work collaboratively, ask questions and solve puzzles. It is an interactive process that requires children to struggle toward goals. The more we engaged in the play, the more we are interested in what we are doing. And through different types of playing, we develop different skills *[Fig 2.2-2]*.

Sensory Play: learning through senses	Exploratory Play: Learning by finding out	Manipulative Play: Learning by touch/feel/handle mould	Dramatic Play: Learning by role-taking/ pretending	Creative Play: Learning by creating
textured/scented/colored play-dough textured/scented/colored water-play textured/colored sand play cooking	mixing colors shades/dark/ light relation between shape spatial relations numbers/ patterns/ sizes	Blocks, lego, duplo, Brush blocks paper-folding cutting/pasting physical	pretending to be people animals/ transport acting out situations role-play	drawing paintings collages printings stories songs music sound patterns

Figure 2.2-2 Types of Playing[65]

The value of learning by playing lies in two parts. The first is immersion, the player takes a new identity and immersed in a counterpart of the real world. "You have to do more than identify with a character on the screen. You must act for the character"[66] That's why learning a foreign language in that country will enhance the learning process, people pick up words more easily. Also when you are playing a game, it is like to create an active and positive environment, you are forced to keep on making decisions almost every second. All of these increase motivation and interest in this given challenge.

65 Katrina Baker, Early Years Team, "Play Based Learning".
66 S. Turkle, Learning through action.

The second is experiential, you practice a lot through playing. Deep learning comes from understanding the relationships among the variables, their actions, the rules and relationships, and results. That kind of learning cannot be achieved with simple rote plays because complex processes are nonlinear and nor procedural.[67] "Replaying the game encourages experimentation as players devise new strategies and interact with the materials in new ways."[68] It also encourage player to dive in and make mistakes as they learn. Since it is not the mathematics or history in the game that is important, it is the knowledge player earns to solve real life problem that really counts. In other words, players must understand what they are doing and develop their comprehension of this subject, and increase the chances of that knowledge transferring to other novel situations.

Kolb's model is a reasonable start to talk about experiential learning *[Fig 2.2-3]*. The basic model is based on People's gaining knowledge through experience transformation. "The particular experience is translated into an abstract conceptualization which is actively tested through new experiences."

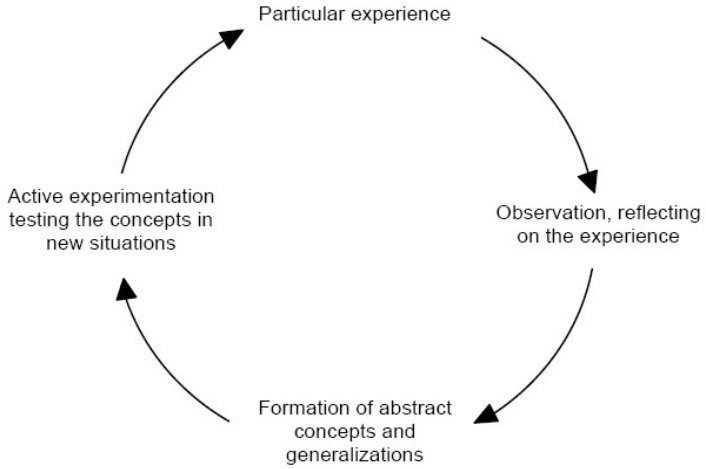


Figure 2.2-3 Kolb's cycle of experiential learning

A "within game" Cycle[69]

1. Experience something discordant: student "makes a move"
2. Reflect and observe the phenomenon: what happened in the game
3. Relate reality to theory – look for a model: *why* did that happen
4. Construct a hypothesis: Plan for next move: this should happen, let's do it

Reflecting on the experience of a game or simulation is known as debriefing. The importance of debriefing as a part of the overall educational process is pivotal in transforming experience into learning (Baker & Jensen, 1997). An effective debriefing session helps the player reflect objectively on the learning experience and gain new knowledge from this reflection. The debriefing can be organized in a number of ways, from an informal or structured discussion to some form of written report or commentary on the experience (Thatcher, 1990).

67 Gloria Gery, Business Services Industry.
68 Hinrichs, Foreman article.
69 Michael Yacci, PhD. Professor, Information Technology. Game-Based Learning: An Introduction.

2.3 Study of Game Simulation Tools

Both in the architectural design and energy education community, numerous tools have been developed. My study of these chosen tools all addresses design issue and energy issue in a game format. I will examine the 4 selected games in greater depth, reveal their unique feature, and compare their specific learning objectives.

2.3.1 Home Design Game

Figure 2.3-1 The Sims™ Livin' Large

The objective of Sim Living, as the name of the game suggests, is to build and design a home, with certain specific goal to achieve *[Fig 2.3-1]*. This pack includes living/buying/building mode and 50 career tracks. Through spatial storytelling, creative design solution will come out in the design of specific environments. As an amateur architect, players immerse in design homes for hours. The game environment is robust enough for the players to design any kinds of interior configuration, taking the dining room depicted here as an example. Players can also create rustic country houses, medieval castles or even Sci-fi future homes. In order to fulfill daily needs, players customized their homes through buying items. Players choose among furniture and appliance, and each decision is depending on the space he encounters, the behavior he develops, and the situation he experiences. Besides, they also make decisions about color, style and pattern of the items they choose.

Social Network Community, **Network game:**

Figure 2.3-2 Habbo hotel[70]

70 http://www.habbo.com/

Habbo Hotel is the largest virtual hangout place aimed at teenagers *[Fig 2.3-2]*; players can design their own room and furniture, throw parties and make friends. The opportunities for creating interactive community make the virtual social networking possible. Habbo Hotel encourages players to actively create items among the social networking, design an environment that constitute these virtual worlds. Because there is no end point, the only motivation for players immerse in the playing is the social interaction. With a strong focus on communication and collaboration between players, Habbo Hotel develops a chatroom with a game-like interface. Players exchange information, experiences and even resources related to an activity or an event. Through modeling our relationships with family, friends and lover, we learn how to deal with everyday conflicts and tension.

2.3.2 Energy Game

Web-based, Energy Management Devices

Figure 2.3-3 Energy Tool: Google Power Meter

Google Power Meter, an energy tool, will receive information from utility smart meters and energy management devices and provide anyone who signs up access to her home electricity consumption right on her iGoogle homepage *[Fig 2.3-3]*. The graph above shows how someone could use this information to figure out how much energy is used by different household activities.[71] This tool introduces a stronger connection on energy and control. "Many of today's smart meters don't display information to the consumer. Google Power Meter takes advantage of our scalable, secure IT architecture and our popular iGoogle gadget platform to show you your energy use in near real-time (and it's free to both utilities and consumers). But empowering consumers with energy information is too important to rely on just one provider, and we welcome and encourage other approaches."

Web-based, Energy Saving Game

Figure 2.3-4 Energy Game: Turn It All Off

71 http://www.google.org/powermeter/

This image from *Turn It All Off* shows how game simulates the daily life and sustainable development and the greenhouse effect *[Fig 2.3-4]*. The objective is to give people insights about energy use with simple daily activity, and to gain awareness of the key issue of living impacts. It is a cute, well-produced game that does more than many similar games I have seen over the years. The principle is familiar enough: move a character around an office and find the objects that are using energy unnecessarily. But Turn It All Off actually ads some gameplay for once: there's a time limit, and there are both obstacles and simple puzzles to overcome. I'll give away the puzzle in the first level to give you an example: turn the coffee pot on to lure the late-nite worker away from her workstation, which you can then turn off.[72]

2.3.3 Comparison Summary

Despite that all of the games above relate to design and energy, the focus is quite different.

Tools –Design Game: Not about energy decision

In the home design game, it employs a simple familiar space home to engage people to simulate living. Players personalize the avatar to represent their identity and come to the online community to interact with each other. But it doesn't teach people about energy issue, and people don't make energy decision.

- No info about energy
- No understanding of green living
- Gameplay has nothing to do with learning
- Gameplay doesn't connect to the real life problem/situation
-

Tools –Energy Game: Not about design decision

While in the energy game, there is no design decision. The reference to the real world directly serves as the underlying model. are simulated according to the processes in the real world.

- No sense about design complexity
- No difficult choices
- Just expose players to tons of task
- Not enough to represent the energy problem
- Not repeat playable

72 Ian Bogost, Turn It All Off, an energy savings game

2.4 From BIM to SIM?

In contrast to the 2D CAD drawing with specifications, BIM interoperability bring developer, owner, designer, constructor, fabricator together around a Building Information Model, and make data transmission between building design, construction, and operations possible, efficient and accurate. Architectural design has become a rule-based game, collaboratively played by different agents and teams. Therefore, I take the challenge to see whether GREEN can be simulated in this game setting, to address the energy issue and sustainable design concept to consumers, architects, decision makers in general.

The use of game-like strategies to benefit learning processes is well-known in education (Dewey 1957), while their potential to enhance architectural education has been suggested by several researchers (Hubbard 1980, Woodbury 2001, Scriver & Wyeld 2001). The game point to what is missing in current workflow in architectural design: Consumer participative home design. People learn, help, cope, innovate etc.

The metaphor:
SIM: City design and planning

- Compare different city planning layout
- Decide land use
- Investigate relationship between industry, commerce, and residential
- Coordinate the politics, laws and management of city
- Increase public safety
- Disaster planning
- Mass and personal transportation
- People: Sims

BIM: Building energy model

- Site/ Orientation
- Construction
- Roofs/ Doors/ Windows/ Glazing
- Thermal
- Hybrid ventilation
- Day-lighting
- Solar
- Eletrical
- Mechanical

2.5 The Learning Tool: A Serious Game

This thesis question is:
Can we design a tool to educate non-experts about energy-related design and decision-making of their homes?

This research examines the potential of **game education** and develops an **immersive learning** environment that supports energy education activities. Through learning by playing, it is able to create a **deep-learning** environment and also **add emotion to the problem-solving** process.

The Goal of the tool is:

- Educational
- Fun
- Energy-based Design and Decision Making
- Energy-based Behavior Change
- Taking advantage of the inexpensive computation, to address problems about participative design, energy consumption, healthy living, sustainability…

The key to incorporate Green is education. This recent trend might be achieved by a learning tool, from which non-experts can be introduced to sustainable design strategies. This tool focus on the specific people: non-expert designer, and the specific needs: sustainability. It would augment the experience of designing a new house by having direct control over the lifetime cost and performance.

The goal to design a healthy comfortable home while considering environmental impact, meeting sustainable design rules and building code, which actually means this is a complex integrated system and cooperative design process. For this specific complicated task, a game might be the best choice to uncover the consumer's needs by simulating the design as easy as possible. When the non-experts participate in the game playing, they can have the control as the experts.

My study of this learning tool builds on BIM and E-learning game. This toolkit will take the energy-related decision-making and behavior change as the motivation and professional design as the database. Through an immersive environment, it will put forward strong-determined proposals to decision makers. The contribution of my work is to educate people about green design, green living and green financing, as an alternative to the commonplace housing estate and its lacking in sustainability.

Through the use of this tool, it may succeed in helping non-experts make appropriate energy decisions. These ways of decision-making give rise to three scenarios:

- The first aims to inform the potential use of space when they design, thereby resulting in a relatively diversified tailor-made home for the consumer. Spaces are not determined

at first place but allow user's free choices. When occupants are very well informed about the use of the space, they will be aware of the potential of changing.

- The second is a integrate design approach that makes low energy homes accessible. The home will become a center of energy conservation and production. Awareness of energy issue will motivate home-based advanced conservation behavior change.
- Finally, the home will become a center of learning. As learning becomes fun, information is at your finger tips, excellent computation will find just the right balance between awareness raise and behavior changes:
  - What sustainable buildings are
  - How sustainable buildings create a healthier living space
  - Your role in promoting energy and cost saving

Chapter 3

Thesis Approach

3.1 BIM Game = BIM + E-learning Game

The question of the learning tool discussed in the previous chapter is, how to transfer the building information into games to evaluate energy performance. One approach is to use Building Information Modeling (BIM) to address all the issues at the same time *[Fig 3.1-1]*. As a famous building information management and parametric modeling tool, BIM is also adopted to provide real-time energy analysis, cost estimation, and building performance simulation in the building life cycle.

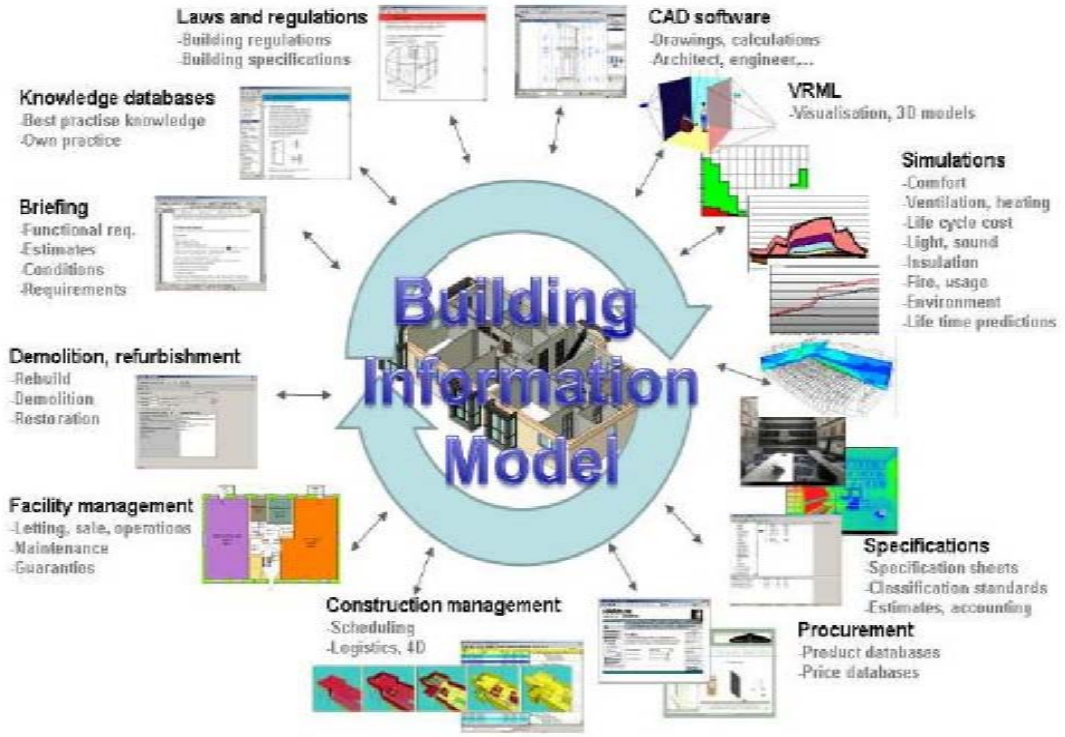


Figure 3.1-1 BIM lifecycle view[73]

Therefore, this thesis proposes a learning tool to integrate BIM and E-learning Game to educate non-experts about energy-related design and living *[Fig 3.1-2]*. The aim is to provide non-experts easy access to the design process, make appropriate decisions, and improve building performance. With the immersive feature of the game, it is able to create a deep-learning environment and also add emotion to the problem-solving process.

The main objective of the learning tool is to:

- Educate non-experts about Energy-based Design and Decision Making
- Educate non-experts about Energy-based Behavior Change

73 building Smart, Deke Smith, Executive Director

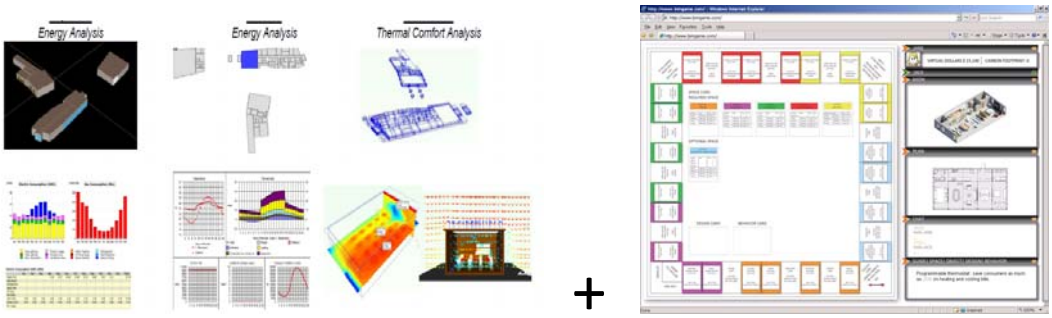


Figure 3.1-2 Proposed model structure: BIM GAME = BIM + E-learning GAME

Platform:
The building modeling and energy analysis is developed using Revit Architecture, a BIM platform, and GBxml, the Autodesk Green Building Studio web service. The participative design interface is built on Flash MX, html and PHP, to experiment and test how to educate the players.

I will use the paper-based prototype to test out the educational value of this game, and the multi-user, web-based prototype to give a further scenario of the game. It will allow the players to log on to the web site, play the game, design their home, calculate Carbon Footprint, and share with friends in the community network.

3.2 Game Structure

The BIM model evaluates the Carbon Footprint of a Revit-based building, using the Green Building Studio plug-in as part of the BIM workflow, while game is applied for environment-behavior simulation. By playing the game, the player insert, extract, update or modify information in the BIM model, and make decisions about home configuration and performance. Better design and sustainable environments can be resulted from this integrated decision-making process and web-enabled data management tool. In this way I will explore game's potential to facilitate consumer driven participative design and its instructive process.

Based on the Game3.0 and Web2.0 technology, the consumer first plays a web-based game in the web-browser. The design information will be transferred real-time to the BIM model, and get predefined configuration. Then the BIM model calculates the Carbon Footprint and cost, and update in the game interface to let user make informed decisions *[Fig 3.2-1]*. Home design for the homeowner is conceived as an iterative learning process of defining perspectives, uncovering needs, and expressing plans for the future, and making personal connections.[74] Through the interactive playing, the consumer will get a first hand of view of the design impact, configuration, energy and cost, and the performance criteria. Also game could be reflective, the learning tool not only teach user design but also let user to reflect about their decisions.

74 Kent Larson,Open Source Building: Reinventing Places of Living

The goal of BIM Game:

• To educate non-experts about how their design and decision-making impact the built environment and how to design the sustainable house of their own, thus change design education from the professionals to all people who care about energy issue and living environment.

• To develop a new responsive model by integrating BIM and game to make public awareness of energy efficiency, Carbon neutral, interior comfort and environmental health, high performance low energy cost, sustainable material and products, etc.

• To explore innovative shifts in industry process for consumer participative design and file-to-factory fabrication strategies, change the role of the consumer from the last benefit end-user to the first decision maker.

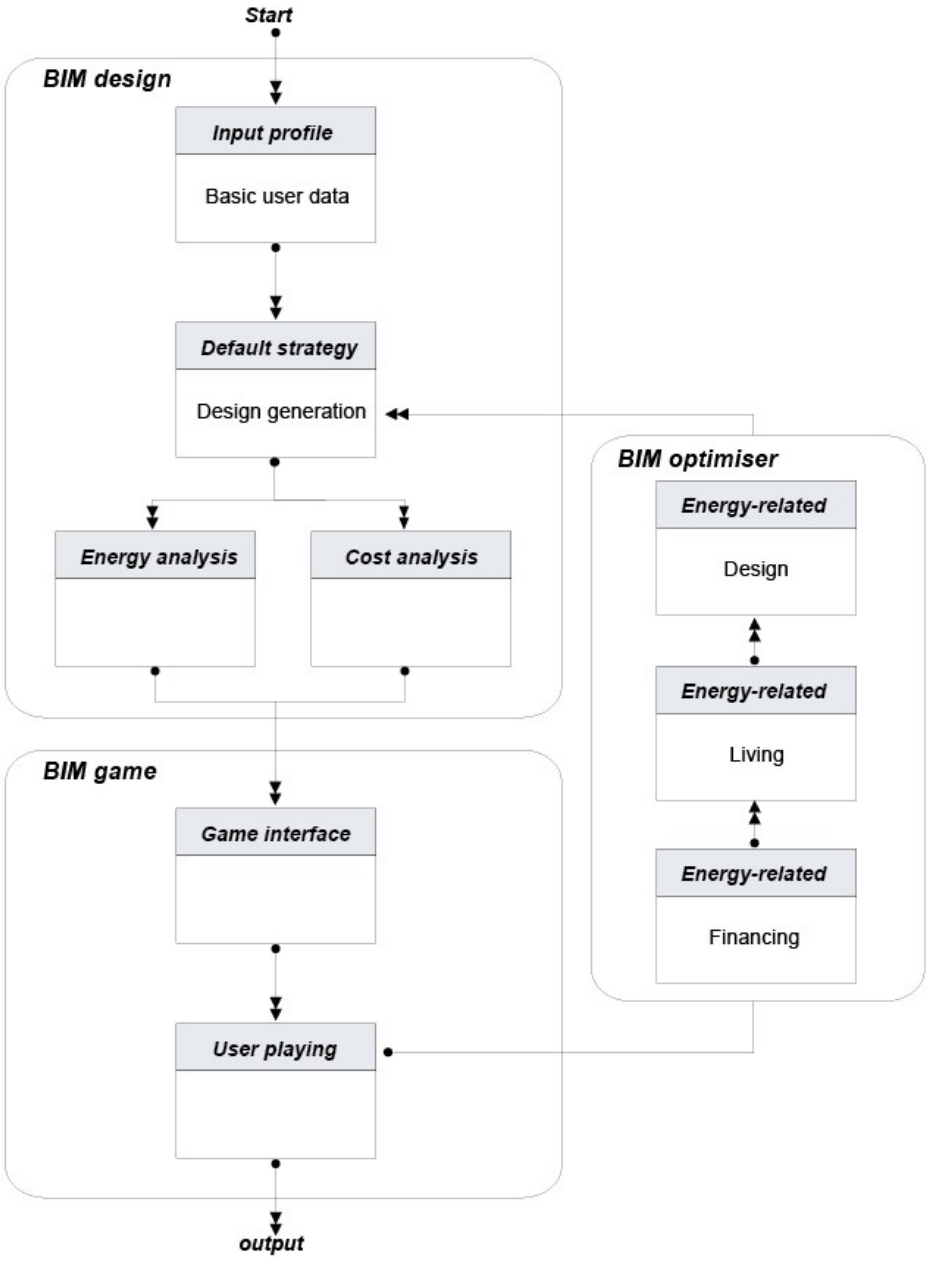


Figure 3.2-1 Home design game loop

3.3 Game Strategy

To see how BIM and Game integrate together, the new model consists of 3 steps.

Step 1:

In the first step, architects provide design strategy within a BIM environment to represent his unique design feature *[Fig 3.3-1]*. This BIM model is a shared digital representation built on standardization, which can facilitate smooth and efficient interoperability. The design can be used as the default design strategy for the next step in the game. So the consumer is not dealing with a totally new home design, the architect have already made enough design decisions to guide the consumer and instilled expert knowledge into the design.

Location:
- Local weather data (heat, cold, solar energy, wind energy)
- Local utility cost (Electric cost: $0.150/kWh, Fuel cost: $1.490/Therm)[75]
- Building code

Building:
- Building type (Multi-family, single family)
- Floor Area
- Occupancy Schedule (24/7 facility, 24/6, …12/5, year-round)[76]
- Family size (1-4, 5-7, 8-12)

Figure 3.3-1 Architect predefined solution

Different architects can contribute by providing their designs, from which a database could be built. Within the database, architects can plug-in different components to enrich the building design engine. Since BIM is an object-oriented and component-based representation tool, it allows the entire domain in the building industry to easily share data. It is like to enable various divisions in a production process to easily share data about a product. Based on the Open Source technology, consumer might have his predefined home design by choosing his favorite architect, or have a hybrid style by choosing many architects *[Fig 3.3-2]*.

Expert	Architects plug-in different components
Architect 1	Component 1
Architect 2	Component 2
Architect 3	Component 3

Figure 3.3-2 Architect predefined design

Step 2:

In the game phase, consumer chooses which architect he prefers and the specific design style. Then he plays the game in the predefined BIM context, and gets the configuration from the default strategy. The whole game simulates the home environment, and could be used to guide the user through home design and buying process *[Fig 3.3-3]*. Instead of making decisions every step by working side by side with an architect, or every day and night on

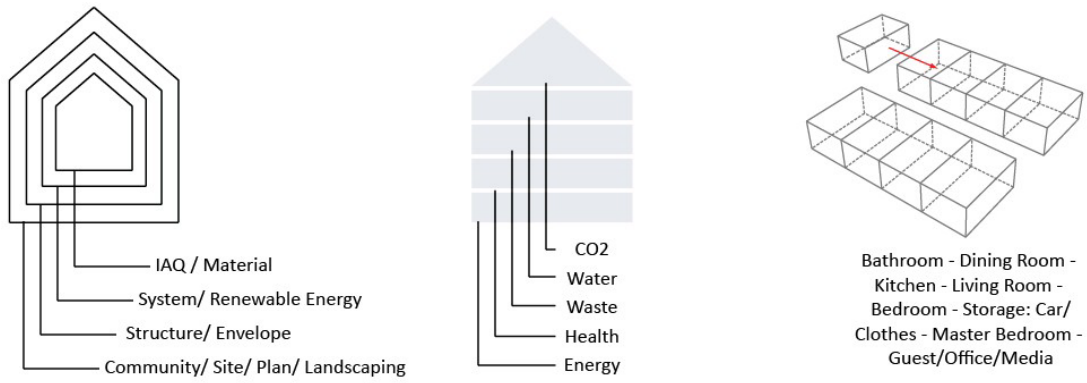
75 Massachusetts state average

76 24/7 facility (Buildings is operating all the time through the year), 24/6 facility (Building is operating 24 hour M-Sat but closed on Sunday), 24/5 facility, 12/7 facility, 12/6 facility, 12/5 facility, Year-round(all through the year except holidays)

which product to choose, consumer makes informed decisions by playing a game *[Fig 3.3-4]*. As the option show below, it also helps the early stage of user's self discovery of needs and preferences.

Non-Expert	Make Informed Decisions about Space, Object, Activity
Design	Space 1
Purchase	Object 1
Behavior	Activity 1
Design	Space 2
Purchase	Object 2

Figure 3.3-3 User playing



Design Decision Behavior Decision Space Decision

Figure 3.3-4 Decision-making

Consumer play, design, and optimize his decision about space, plan, energy efficient product, and also get cost and feedback during the conceptual design phase. Game is easy for non-experts, so they don't really need to think like expert designers within a modeling environment. From the player's input, the output from the default design matches the player's requirement.

Composed of design rules, the game allows the players to add a space, configure a space, add objects, and decide living ways *[Fig 3.3-5]*. The three main decisions include:
1) Design decision; 2) Purchase decision, 3) Behavior decision.

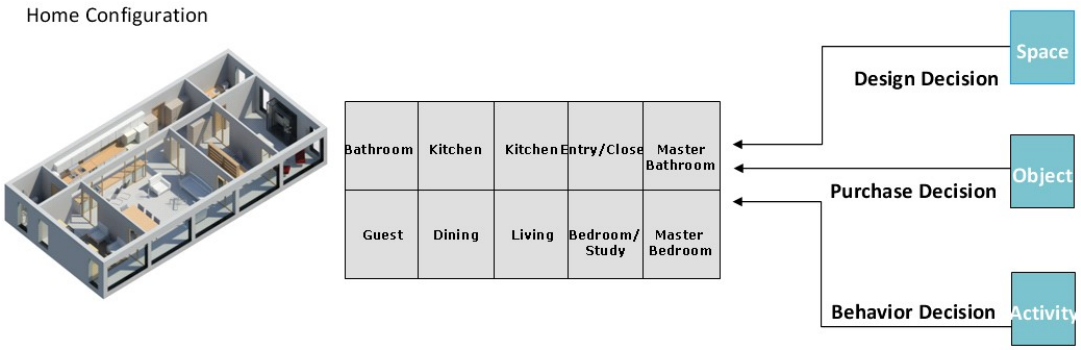


Figure 3.3-5 Design activities

1) Design decision:

Add a Space:

A compact home may have only a bathroom, a bedroom, while a luxury one may have 4 bedrooms and 2 living rooms. The player can think through what type of room they may need, and study into detail how to evaluate between the size and Carbon Footprint of the space *[Fig 3.3-6]*.

Space	Size	Price	Carbon Footprint
Small	ft	$	C
Medium	ft	$$	CC
Large	ft	$$$	CCC
Luxury	ft	$$$$	CCCC

Figure 3.3-6 Space decisions

Configure a space:

After selecting certain size of spaces, the player will decide what kind of design could be possible for what kind of space *[Fig 3.3-7]*. The components the player can compare with are orientation, glazing, roof, plan, window, etc. (E.g. A different building orientation, a lower U-value window glazing, or a 4-pipe fan coil HVAC system.)

Appliance	Initial Cost	Lifetime Cost	Carbon Footprint
North Orientation	$	$$	CCC
South Orientation	$$	$	CC

Figure 3.3-7 Trade off

2) Purchase decision:

Sample decisions include: trade-off between lifetime cost and initial budget *[Fig 3.3-8]*, compare resources about more efficient strategies between similar solution *[Fig 3.3-9]*, etc. Some choices minimize Carbon Footprint but cost more money, and vice versa. Negotiations and trade-off exist in the whole playing phase.

Add an object:

Appliance	Price	Payback years	Carbon Footprint
App 1	$	YYY	CCC
App 2	$$	YY	CC
App 3	$$$	Y	C

Figure 3.3-8 Trade off

Add an energy solution:

Appliance	Price	Payback years	Carbon Footprint
Solar water	$	YYY	CC
Solar PV panel	$$	YY	C

Figure 3.3-9 Compare

3) Behavior decision:

Sample decisions include: evaluate the energy use in home and transportation, etc *[Fig*

3.3-10]. (E.g. Replace Regular Light Bulbs With Compact Fluorescent Lamps (CFL's))

Behavior	Carbon Footprint
Behavior 1	Reduce CC
Behavior 2	Increase C

Figure 3.3-10 Behavior Impact

In addition to add space and make purchase decisions, other tools enable player to get instant feedback about his home design. Carbon Footprint and cost will be shown to the player according to the design change. Through a combination of multiple visualization tools, it provides information for the player to make informed decisions about uses of space, sustainable products, and behavior impact.

Since aesthetic is open ended and difficult to evaluate, the work here only address the Carbon Footprint which could be quantify. Players will be informed by their design in terms of Carbon Footprint, which means the more you reduce carbon emission, the less Carbon Footprint your home will get. They also learn the general design strategies and related solutions in an interactive and fun way. Through learning by playing, it allows the consumer to explore and learn about green design and post-occupancy sustainable living. In the multi-player game, different home improvement strategies can lead to diverse building performance. The player also can see how other players use energy and manage resources.

Step 3:
Finally, all the information the player made will be transferred back to the BIM model, and pass on the result to the architect. Because the BIM data can be shared directly, architects make professional modifications and finish the design, and then pass on the design to manufactures. Therefore, architects and developers can build customized homes for the consumer directly.

3.4 Carbon Cost Ratio

In this game demon, we only consider two parameters: cost and Carbon Footprint *[Fig 3.4-1]*. That makes the choice much simpler. But in the real life, there will be more decision factors to be considered or needs to be satisfied, say, performance cost ratio. Therefore, this game provides us a good opportunity to make our choice fun and easy.

$$Relative\ Carbon\ Cost\ Ratio(RCCR) = \frac{Intial\ Carbon\ Footprint - \Sigma_{i=1}^{N} \Delta\ Carbon\ Footprint^{(i)}}{Budget - \Sigma_{i=1}^{N} \Delta Cost^{(i)}} \quad (1)$$

$$Item\ Carbon\ Cost\ Ratio(ICCR) = \frac{\Delta\ Carbon\ Footprint}{\Delta Cost} \quad (2)$$

Figure 3.4-1 Carbon Cost Equation

Carbon Cost Ratio refers to a product's Carbon Footprint reduce to its price *[Fig 3.4-1 (2)]*. For example, if you have LED light cost $100 with Carbon Footprint 1, and a Low-flow showerhead cost $100 with Carbon Footprint 4, spending $100 on Low-flow showerhead is a better deal.

The "Carbon Footprint" CF, the carbon emission of each object, is weighed according to the following formula[77]:
a) Energy Use: 30% b) Water Use: 30% c) Carbon Dioxide: 20% d) Trash Production: 10% e) Wastewater Production: 5% f) Runoff Production: 5%
Calculated as: CF = a *30% + b*30% + c *20% + d*10% + e*5% + f*5%
For example, Low-flow showerheads have the following value:
a) Energy Savings: 41 therms b) Water Savings: 5475 gallons c) Waste Savings: 0 lbs d) CO2 Savings: 477 lbs e) Runoff Savings: 0 gallons f) Payback Period: 0.6 years
CF = 3.8 *(1CF = 10 therms of natural gas = 10.9 gallons of propane = 7.2 gallons of heating oil = 294 kilowatt-hours of electricity.)*

In some cases, specific cost is provided. In other cases, relative cost, lifetime cost or annually saving is given. Actual number may vary considerably among locations, time and will depend on availability.

77 http://www.lowimpactliving.com/pages/green-projects/green-projects

Chapter 4

BIM System

4.1 Open Source

Since BIM is an object-oriented and component-based representation tool, it allows the entire domain in the building industry to easily share data. Within the database, architects can plug-in different components to enrich the building design engine *[Fig 4.1-1]*. Based on the logic between different spaces *[Fig 4.1-2]*, it can finally get into the house assemblies.

Predefined Solution:

Expert	(Architects plug-in different components)
Architect 1:	Component 1
Architect 2:	Component 2
Architect 3:	Component 3
Architect 4	Component 4
Architect 5	Component 5

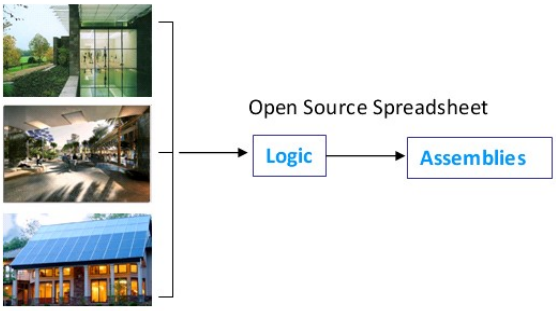
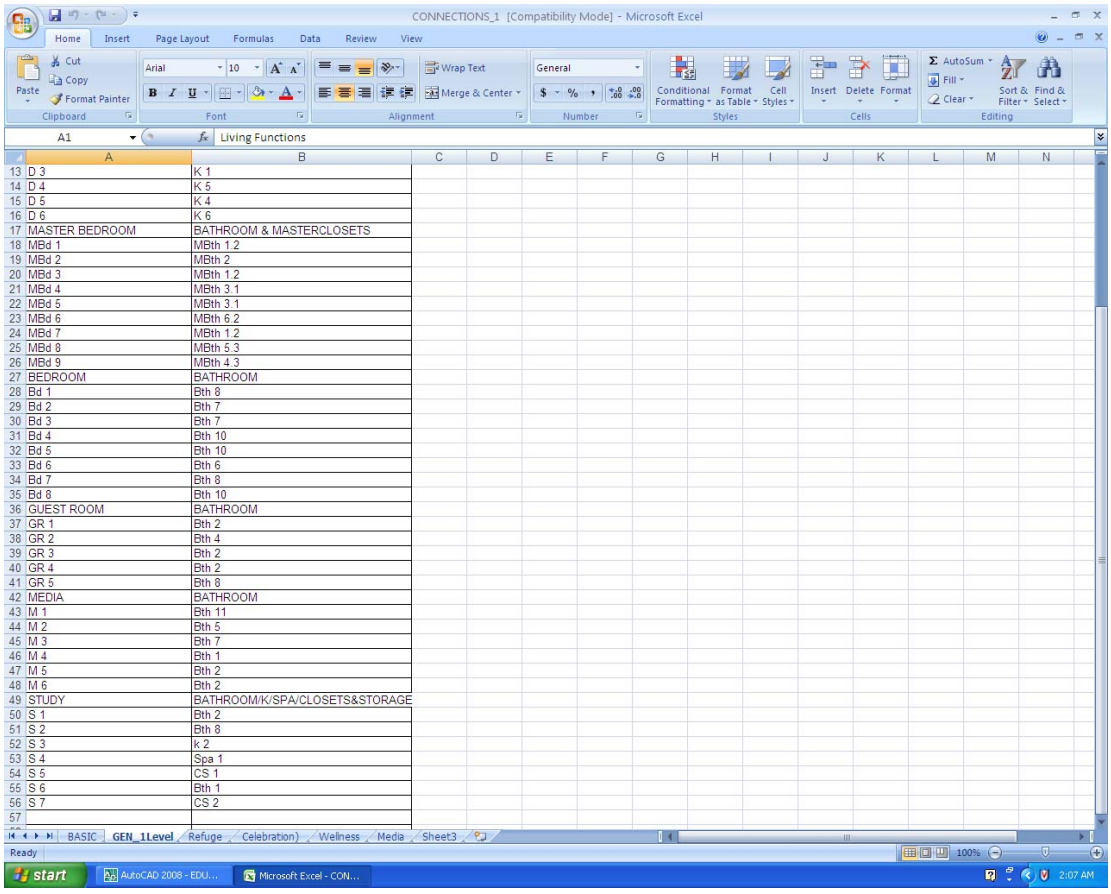


Figure 4.1-1 BIM Open Source



13	D 3	K 1
14	D 4	K 5
15	D 5	K 4
16	D 6	K 6
17	MASTER BEDROOM	BATHROOM & MASTERCLOSETS
18	MBd 1	MBth 1.2
19	MBd 2	MBth 2
20	MBd 3	MBth 1.2
21	MBd 4	MBth 3.1
22	MBd 5	MBth 3.1
23	MBd 6	MBth 6.2
24	MBd 7	MBth 1.2
25	MBd 8	MBth 5.3
26	MBd 9	MBth 4.3
27	BEDROOM	BATHROOM
28	Bd 1	Bth 8
29	Bd 2	Bth 7
30	Bd 3	Bth 7
31	Bd 4	Bth 10
32	Bd 5	Bth 10
33	Bd 6	Bth 6
34	Bd 7	Bth 8
35	Bd 8	Bth 10
36	GUEST ROOM	BATHROOM
37	GR 1	Bth 2
38	GR 2	Bth 4
39	GR 3	Bth 2
40	GR 4	Bth 2
41	GR 5	Bth 8
42	MEDIA	BATHROOM
43	M 1	Bth 11
44	M 2	Bth 5
45	M 3	Bth 7
46	M 4	Bth 1
47	M 5	Bth 2
48	M 6	Bth 2
49	STUDY	BATHROOM/K/SPA/CLOSETS&STORAGE
50	S 1	Bth 2
51	S 2	Bth 8
52	S 3	k 2
53	S 4	Spa 1
54	S 5	CS 1
55	S 6	Bth 1
56	S 7	CS 2
57		

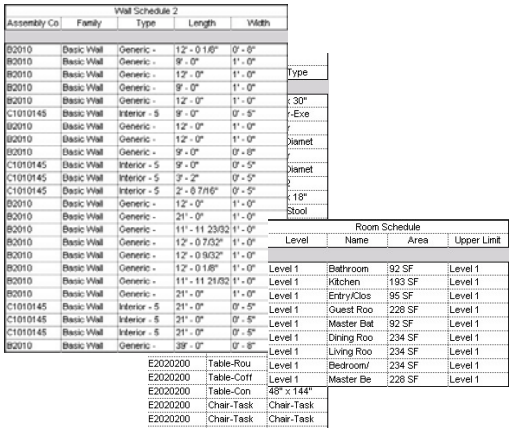
Figure 4.1-2 Open Source Logic (Jonathan Ward, Kent Larson)

4.2 Carbon Footprint

4.2.1 Home Design Demo: Digital Model Preparation

In order to get a picture how these tools work together and how to calculate the Carbon Footprint and improves the initial design, I try a home demo to validate this process *[Fig 4.2-1]*. The study is constrained to a simplified context: a middle-income, US-based, single family detached dwelling with basic selected functions. The plan layout comprises two linear functional zones, one is for mechanical, and another is for living. The internal layout of the dwelling provides the user with basic activity like sleeping, cooking, and working, with kitchen, dining, living room all open to each other. As soon as the layout of a building's walls, windows, roofs, floors and interior partitions (elements that define a building's thermal zones) are established, the information used to create a Revit model can be used to perform whole building analyses.[78] Since the demo only focuses on how the final result influences the design decision-making, other information like context, aesthetics, and family type is not considered too much here.

Figure 4.2-1 Isometric view of the Home Demo



Wall Schedule 2

Assembly Co	Family	Type	Length	Width
B2010	Basic Wall	Generic -	12' - 0 1/8"	0' - 8"
B2010	Basic Wall	Generic -	9' - 0"	1' - 0"
B2010	Basic Wall	Generic -	12' - 0"	1' - 0"
B2010	Basic Wall	Generic -	9' - 0"	1' - 0"
B2010	Basic Wall	Generic -	12' - 0"	1' - 0"
C1010145	Basic Wall	Interior - 5	9' - 0"	0' - 5"
B2010	Basic Wall	Generic -	12' - 0"	1' - 0"
B2010	Basic Wall	Generic -	12' - 0"	1' - 0"
B2010	Basic Wall	Generic -	9' - 0"	0' - 8"
C1010145	Basic Wall	Interior - 5	9' - 0"	0' - 5"
C1010145	Basic Wall	Interior - 5	3' - 2"	0' - 5"
C1010145	Basic Wall	Interior - 5	2' - 8 7/16"	0' - 5"
B2010	Basic Wall	Generic -	12' - 0"	1' - 0"
B2010	Basic Wall	Generic -	21' - 0"	1' - 0"
B2010	Basic Wall	Generic -	11' - 11 23/32"	1' - 0"
B2010	Basic Wall	Generic -	12' - 0 7/32"	1' - 0"
B2010	Basic Wall	Generic -	12' - 0 9/32"	1' - 0"
B2010	Basic Wall	Generic -	12' - 0 1/8"	1' - 0"
B2010	Basic Wall	Generic -	11' - 11 21/32"	1' - 0"
B2010	Basic Wall	Generic -	21' - 0"	1' - 0"
C1010145	Basic Wall	Interior - 5	21' - 0"	0' - 5"
C1010145	Basic Wall	Interior - 5	21' - 0"	0' - 5"
C1010145	Basic Wall	Interior - 5	21' - 0"	0' - 5"
B2010	Basic Wall	Generic -	39' - 0"	0' - 8"

Type
: 30"
r-Exe
/
Diamet
/
Diamet
:
: 18"
Stool

Room Schedule

Level	Name	Area	Upper Limit
Level 1	Bathroom	92 SF	Level 1
Level 1	Kitchen	193 SF	Level 1
Level 1	Entry/Clos	95 SF	Level 1
Level 1	Guest Roo	228 SF	Level 1
Level 1	Master Bat	92 SF	Level 1
Level 1	Dining Roo	234 SF	Level 1
Level 1	Living Roo	234 SF	Level 1
Level 1	Bedroom/	234 SF	Level 1
Level 1	Master Be	228 SF	Level 1

E2020200	Table-Rou	Level 1
E2020200	Table-Coff	Level 1
E2020200	Table-Con	48" x 144"
E2020200	Chair-Task	Chair-Task
E2020200	Chair-Task	Chair-Task

Figure 4.2-2 Schedule, furniture schedule, and room schedule from Revit Architecture 2009

78 www.ideateinc.com/products/brochures/2010/bim_and_sustainable_analysis_2010.pdf

The digital model is prepared in Revit Architecture 2009 with plan, building geometry, connection between space, furniture and openings *[Fig 4.2-2]*. The construction materials include basic wall_generic 12", interior wall 5" partition, concrete ceiling and glazing, etc. All of them come from the built-in library in Revit. Finally the data will be exported as GBxml file and processed to Green Building Studio for energy analysis *[Fig 4.2-3]*.

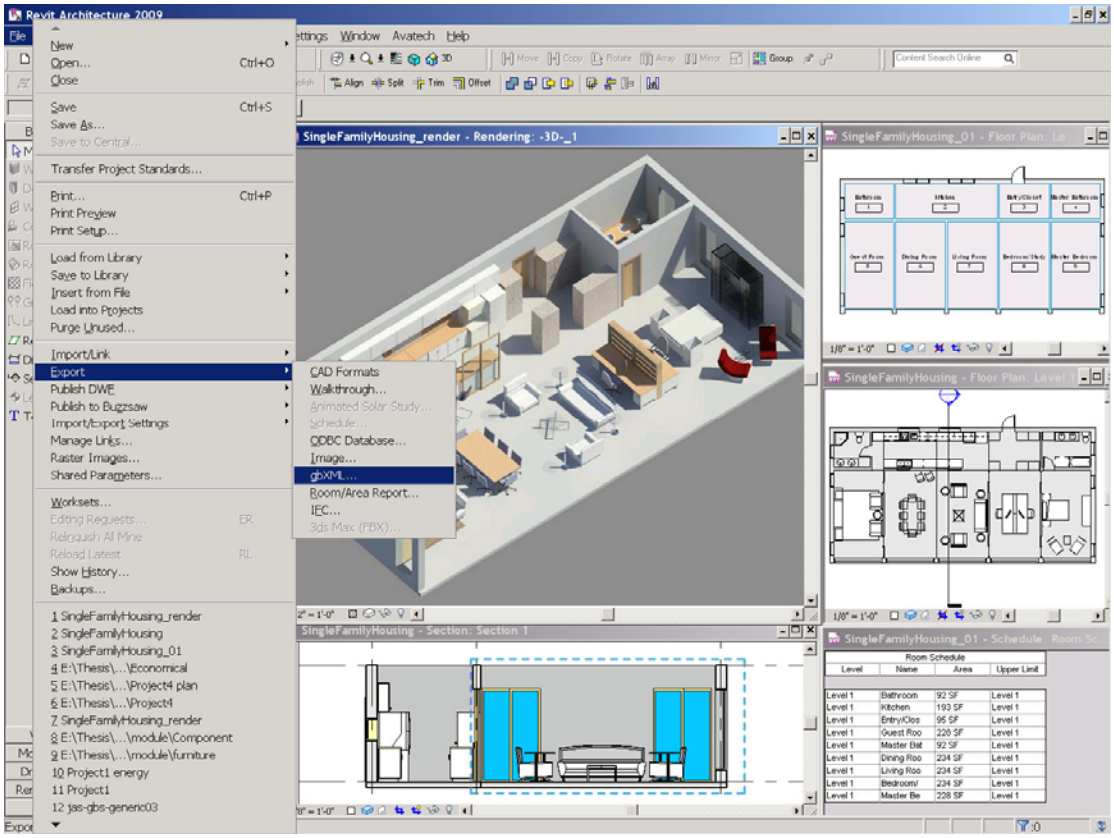


Figure 4.2-3 Export as the GBxml file

4.2.2 Exporting to Green Building Studio

Step 1: Specify a building type: Single Family *[Fig 4.2-4]*

Figure 4.2-4

Step 2: Put the building into context *[Fig 4.2-5, Fig 4.2-6]*:

Green Building Studio incorporates Google™ Maps to select desired site/ zip code/ weather condition. The hypothetical location of this demo home is in one community in Central Square, Cambridge.

Figure 4.2-5

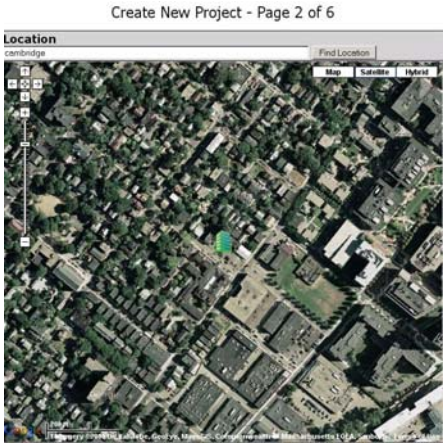


Figure 4.2-6

Step 3: Choose weather station *[Fig 4.2-7]*:

The weather data is based on 30-year average weather data of the area, usually by default the station closest to the building is selected. Weather: GBS_04R20_266135.

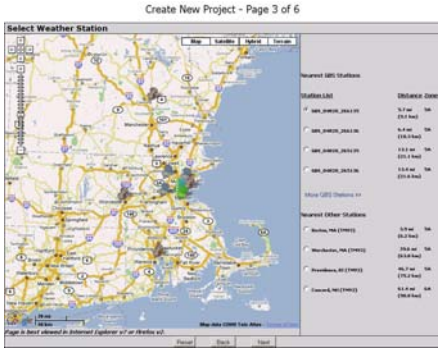


Figure 4.2-7

Step 4: Choose weather station *[Fig 4.2-8]*:

Based on the previous year's state average prices for fuel and electricity, Autodesk Green Building Studio adds information about utility cost, construction, material, and local building code. In this situation, the electric cost is 0.163 $0.00/kwh, while the fuel cost is 1.686 $0.00/Therm.

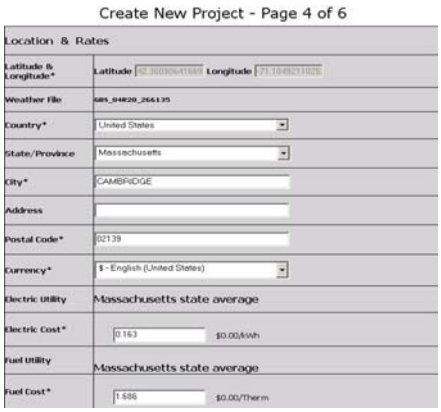


Figure 4.2-8

Step 5: Other info *[Fig 4.2-9]*:

Decide the budget, current design phase, the estimated construction start date, and the green building goal.

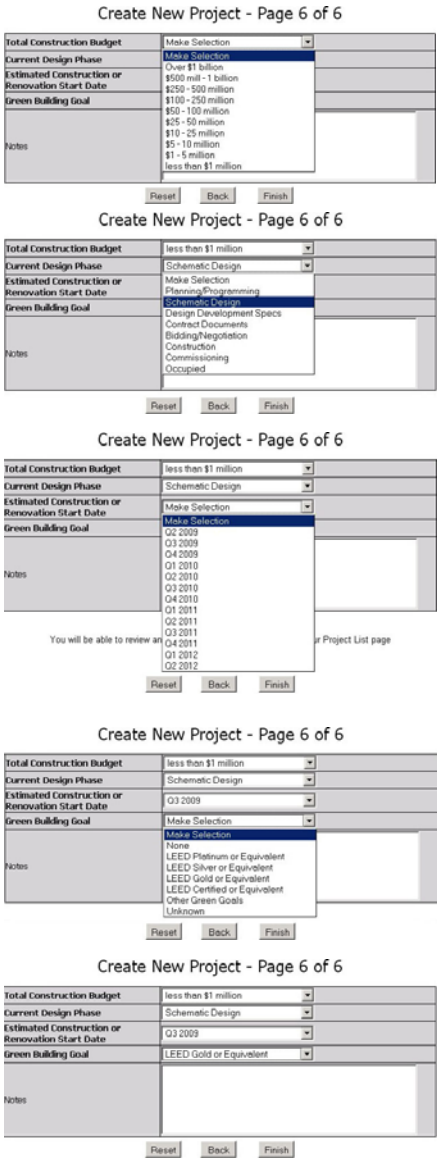


Figure 4.2-9

Then the program initiates the simulations and gets results.

4.2.3 Carbon Footprint Calculation in GBxml

The Green Building Studio results pages provide accurate yet easy-to-understand summary information on building energy and resource use, carbon emissions, simulation assumptions, performance metrics, and costs that can be used immediately to compare the energy costs of multiple building design scenarios at the conceptual design stage.[79]

General Information *[Fig 4.2-10]*:
Building Type: Single Family, Floor Area: 1,628 ft², Location: CAMBRIDGE, MA 02139
Estimated Energy and Cost Summary:

- Annual Energy cost: $8,552
- Lifecycle energy cost: $116,478 (30 years).
- Annual energy consumption (electric and gas): Electric 10,170 kWh Fuel 4,089 Therms
- Peak electric demand (kW): 2.6 kW
- Lifecycle energy consumption (electric and gas): Electric 305,095 kWh, Fuel 122,674 Therms
- An equivalency using an SUV (driven 15,000 miles/year) is given to put the building's CO2 emissions into perspective: 2.6 Large SUV's

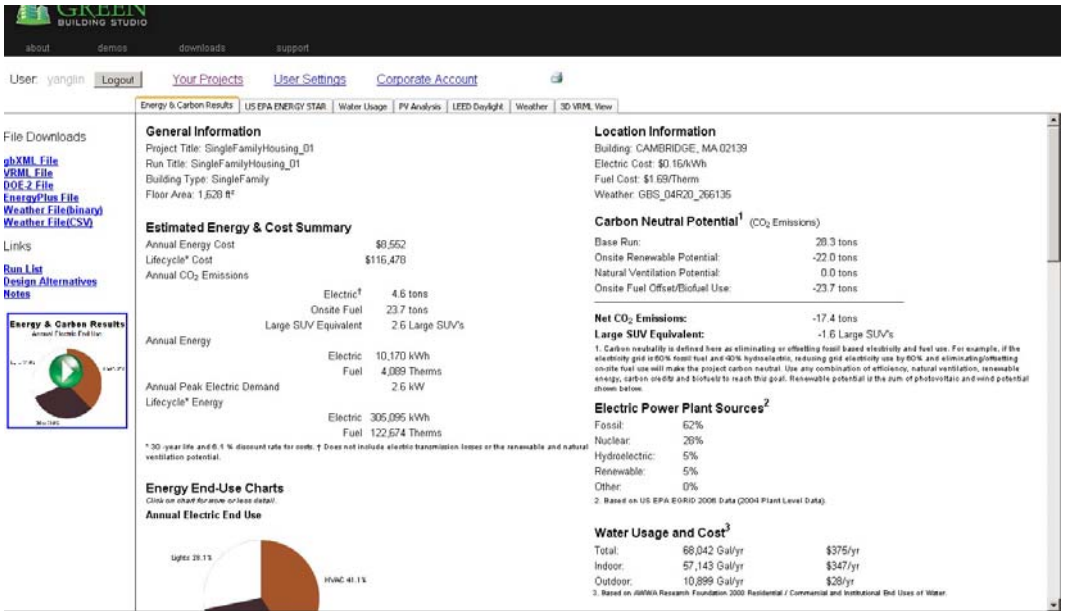


Figure 4.2-10 Energy & cost results

Energy End-Use Charts: Further breakdowns of energy use for major electric and gas end uses such as lighting, HVAC, and space heating are provided in graphical format *[Fig 4.2-11]*.
Building Summary: Detailed statistics, assumptions, and information on building constructions are also provided. This information allows the building designer to get an early assessment of code compliance and rough estimates of equipment sizing requirements for heating, cooling, and water heating, as well as window, wall, and floor area breakdowns.[80]

79 Autodesk® Green Building Studio®, Using Green Building Studio with Revit Architecture and Revit MEP.
80 Autodesk® Green Building Studio®, Using Green Building Studio with Revit Architecture and Revit MEP.

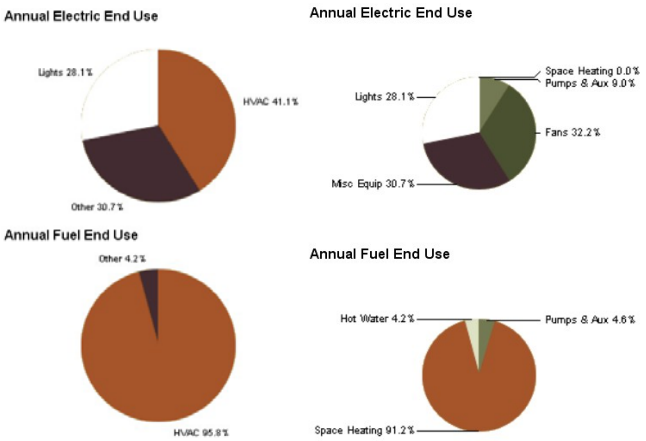


Figure 4.2-11 Energy End-Use Charts

It also calculates the Carbon Footprint of the building and gives the Carbon Neutral Potential. It summarizes the CO2 emissions with the base run 28.3 tons, and the option to reduce it, which is Onsite Renewable Potential: -22.0 tons and Onsite Fuel Offset/ Biofuel Use: -23.7 tons. The Net CO2 Emissions is -17.4 tons, which means great potential to be carbon neutral *[Fig 4.2-12]*.

Carbon Neutral Potential[1] (CO_2 Emissions)

Base Run:	28.3 tons
Onsite Renewable Potential:	-22.0 tons
Natural Ventilation Potential:	0.0 tons
Onsite Fuel Offset/Biofuel Use:	-23.7 tons
Net CO_2 Emissions:	-17.4 tons
Large SUV Equivalent:	-1.6 Large SUV's

1. Carbon neutrality is defined here as eliminating or offsetting fossil based electricity and fuel use. For example, if the electricity grid is 60% fossil fuel and 40% hydroelectric, reducing grid electricity use by 60% and eliminating/offsetting on-site fuel use will make the project carbon neutral. Use any combination of efficiency, natural ventilation, renewable energy, carbon credits and biofuels to reach this goal. Renewable potential is the sum of photovoltaic and wind potential shown below.

Electric Power Plant Sources[2]

Fossil:	62%
Nuclear:	28%
Hydroelectric:	5%
Renewable:	5%
Other:	0%

2. Based on US EPA EGRID 2006 Data (2004 Plant Level Data).

Water Usage and Cost[3]

Total:	68,036 Gal/yr	$376/yr
Indoor:	57,137 Gal/yr	$347/yr
Outdoor:	10,899 Gal/yr	$28/yr

3. Based on AWWA Research Foundation 2000 Residential/Commercial and Institutional End Uses of Water.

Photovoltaic Potential[4]

Annual Energy Savings:	27,342 kWh
Total Installed Panel Cost:	$269,376.92
Nominal Rated Power:	34 kW
Total Panel Area:	2619 ft^2
Maximum Payback Period:	40 yrs @ $0.16 / kWh

4. Results based on all exterior surfaces being analyzed. Escalation rate of 2% applied to electric rate. Payback calculation does not include federal or state incentives, loan information, or tax breaks.

LEED Daylight[5]

Area w/ Glazing Factor > 2%:	0.0% - No LEED Credit

5. Glazing Factor is the ratio of exterior illumination to interior illumination and is calculated using floor area, window geometry (area and height) and visible transmittance of the glass. The project qualifies if glazing factor is > 2% in a minimum of 75% of all regularly occupied areas.

Wind Energy Potential[6]

Annual Electric Generation:	2,969 kWh

6. A single 15 ft diameter turbine, with cut-in and cut-out winds of 6 mph and 45 mph respectively, and located at the coordinates of the weather data.

Natural Ventilation Potential[7]

Total Hours Mech. Cooling Required:	0 Hours
Possible Natural Ventilation Hours:	0 Hours
Possible Annual Electric Energy Savings:	0 kWh
Possible Annual Electric Cost Savings:	$0.00
Net Hours Mech. Cooling Required:	0 Hours

Figure 4.2-12 Carbon Neutral Potential

4.2.4 Design Alternative and Improvement

Design alternative allows people to select a tab and choose from the top-down menu, change the design solution and simulate the impact of changes simultaneously *[Fig 4.2-13]*. Continue doing this and compare the results until all the desired alternatives are added. It allows significant design decisions to be made in very little time.

Real-time performance feedback during design can not only improve the building but also educate designers. “You see the changes and understand what’s going on. It’s not just spitting out numbers—the process of using an iterative tool is educational for us,” Leary reported.[81]

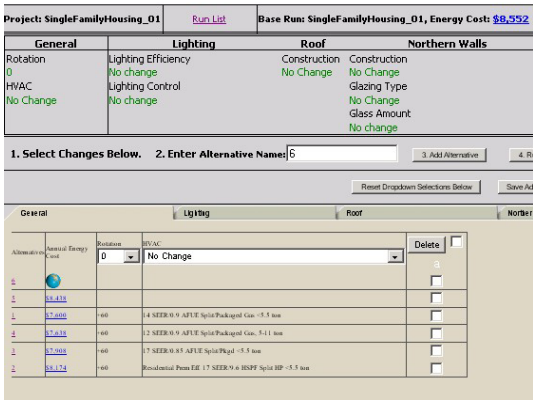


Figure 4.2-13 Green Building Studio Design Alternatives

Design Alternative can enable to interactively explore the energy cost implications of your decisions *[Fig 4.2-14]*.

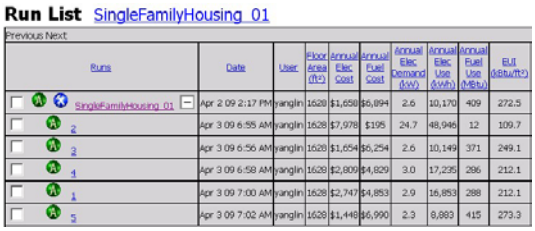


Figure 4.2-14 Run List page

Design Alternative *[Fig 4.2-15]*:

Base Run: Energy Cost: $8,552

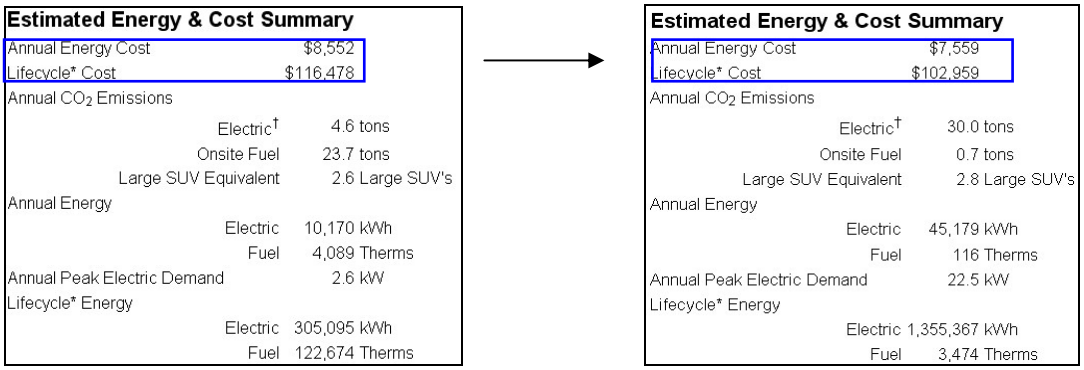
Run list: 1, Energy Cost: $7,559

Project: SingleFamilyHousing_01	Run List	Base Run: SingleFamilyHousing_01, Energy Cost: $8,552			Project settings	
General	**Lighting**	**Roof**	**Northern Walls**	**Southern Walls**	**Western Walls**	**Eastern Walls**
Rotation +60 HVAC Residential Prem Eff. 17 SEER/9.6 HSPF Split HP <5.5 ton	Lighting Efficiency LPD 40% less than base run Lighting Control Occupancy/Daylighting sensors & controls	Construction Wood Frame Roof with Super High Insulation	Construction Massive Wall with Super High Insulation Glazing Type Super Insulated 3-pane Clear Low-e Glass Amount No change	Construction Massive Wall with Super High Insulation Glazing Type No Change Glass Amount No change	Construction Massive Wall with Super High Insulation Glazing Type No Change Glass Amount No change	Construction Massive Wall with Super High Insulation Glazing Type No Change Glass Amount No change

Figure 4.2-15 Design Alternatives

81 Building Information Modeling and Green Design

Example *[Fig 4.2-16]*:
Rotation: +60 $8,509
HVAC: Residential Prem Eff. 17 SEER/9.6 HSPF Split HP <5.5 ton $8,174
HVAC: 17 SEER/0.85 AFUE Split/Pkgd <5.5 ton $7,908
HVAC: 12 SEER/0.9 AFUE Split/Packaged Gas, 5-11 ton$7,638
Lighting Efficiency: LPD 40% less than base run
Lighting Control: Occupancy/Daylighting sensors & controls $8,438
Roof Construction: Continuous Deck Roof with Super High Insulation $8,922
Roof Construction: Wood Frame Roof with Super High Insulation $8,368
Roof Construction: Metal Frame Roof with Super High Insulation $8,368
Northern Walls: Massive Wall with Super High Insulation, Glazing Type: Super Insulated 3-pane Clear Low-e $8,420



Estimated Energy & Cost Summary

Annual Energy Cost	$8,552
Lifecycle* Cost	$116,478
Annual CO_2 Emissions	
Electric†	4.6 tons
Onsite Fuel	23.7 tons
Large SUV Equivalent	2.6 Large SUV's
Annual Energy	
Electric	10,170 kWh
Fuel	4,089 Therms
Annual Peak Electric Demand	2.6 kW
Lifecycle* Energy	
Electric	305,095 kWh
Fuel	122,674 Therms

Estimated Energy & Cost Summary

Annual Energy Cost	$7,559
Lifecycle* Cost	$102,959
Annual CO_2 Emissions	
Electric†	30.0 tons
Onsite Fuel	0.7 tons
Large SUV Equivalent	2.8 Large SUV's
Annual Energy	
Electric	45,179 kWh
Fuel	116 Therms
Annual Peak Electric Demand	22.5 kW
Lifecycle* Energy	
Electric	1,355,367 kWh
Fuel	3,474 Therms

Figure 4.2-16 Left (a): Initial design. Right (b): Design optimization proposal.

"Green" can't be added to a building in a later time in the design cycle. Most of energy calculation is conducted very late in the design process, when other building features cannot be changed. This evaluates the Carbon Footprint of a Revit-based building design using the Green Building Studio plug-in as part of the BIM workflow, to support the decision-making about the project earlier in the design cycle.

Chapter 5

Design and Development of BIM Game

5.1 Game Concept

I design the learning tool using game to teach non-experts about decision-making and critical thinking. Based on 3 game elements (1) space, (2) object, (3) behavior, the goal of the game is to enable non-experts to interpret design solution, enhance the awareness of energy decision-making, and encourage his behavior change later in life.

Since this is part of the collaborative design in the pre-design stage, I have to consider carefully how to simulate the details about the design experience. What kind of games could be easily grasped and played by people from almost all level and age? Where could it take place? What kind of information could be used to adequately reflect ideas about energy saving? What could be a possible reward like the money or upgrade level? How to abstract core issues relate to important skills for green living?

I devised two prototypes of "BIM Game," so far, using paper prototype and HTML respectively to test the game concept. In this prototype, I will try to make the game fun and instructive, and test the game playing and game-based learning, so graphics or storytelling is not my concern. There will be several different situations the player might encounter, and they can also chat to see how each other control their decision. I will collect user's response and feedback and incorporate my own evaluation for the design iteration stage of the game.

The study will explorer player's learning interest and raise the awareness of sustainability, rather than to teach them a set of defined terms. Players learn the benefits, costs and rewards of alternative strategies that result from decision making. I will also test whether this concept holds or has to be modified to fulfill the criteria described above.

5.1.1 Game Prototype

Web prototype interface:
This proposed design interface is an in-browser game interface with multiple visualization *[Fig 5.1-1]*:

- An game interface
- Player info (Virtual Dollar, Carbon Footprint)
- 3D visualization
- 2D plan
- Chat window
- Guide (Good or Bad choice)

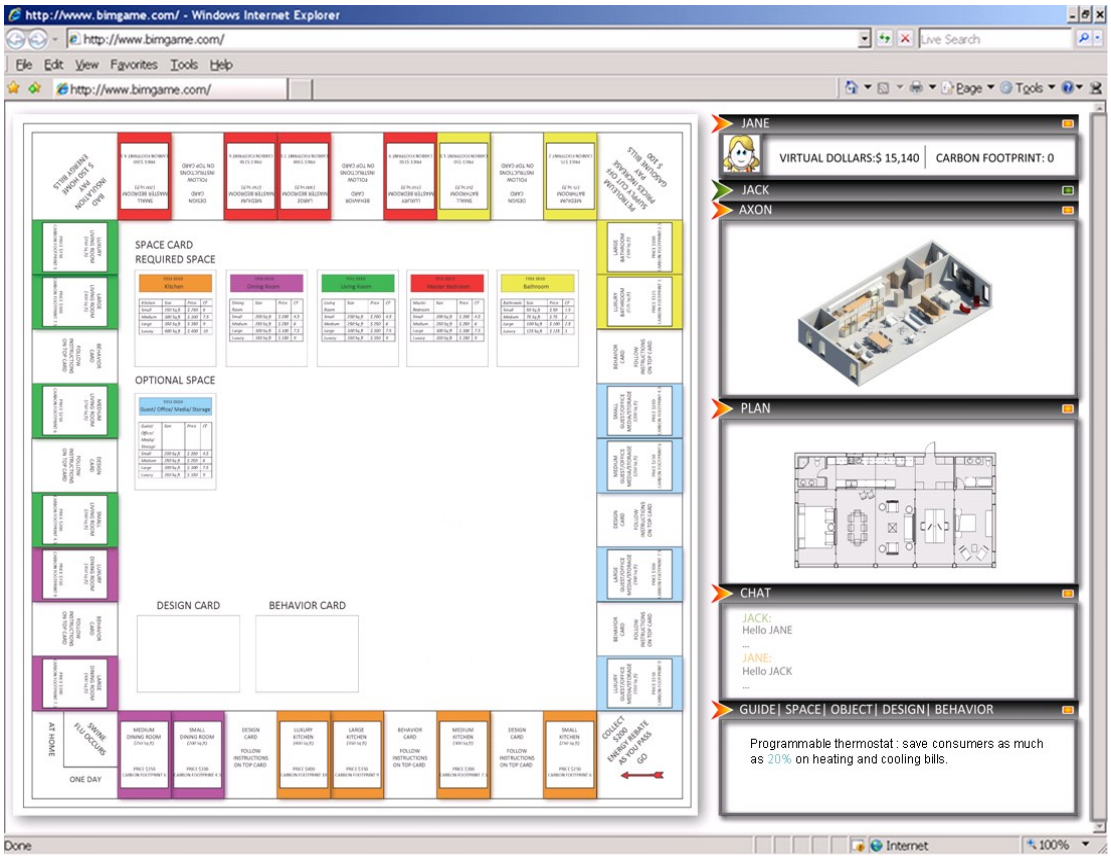


Figure 5.1-1 Prototype 1: Web Game interface

Paper prototype interface:

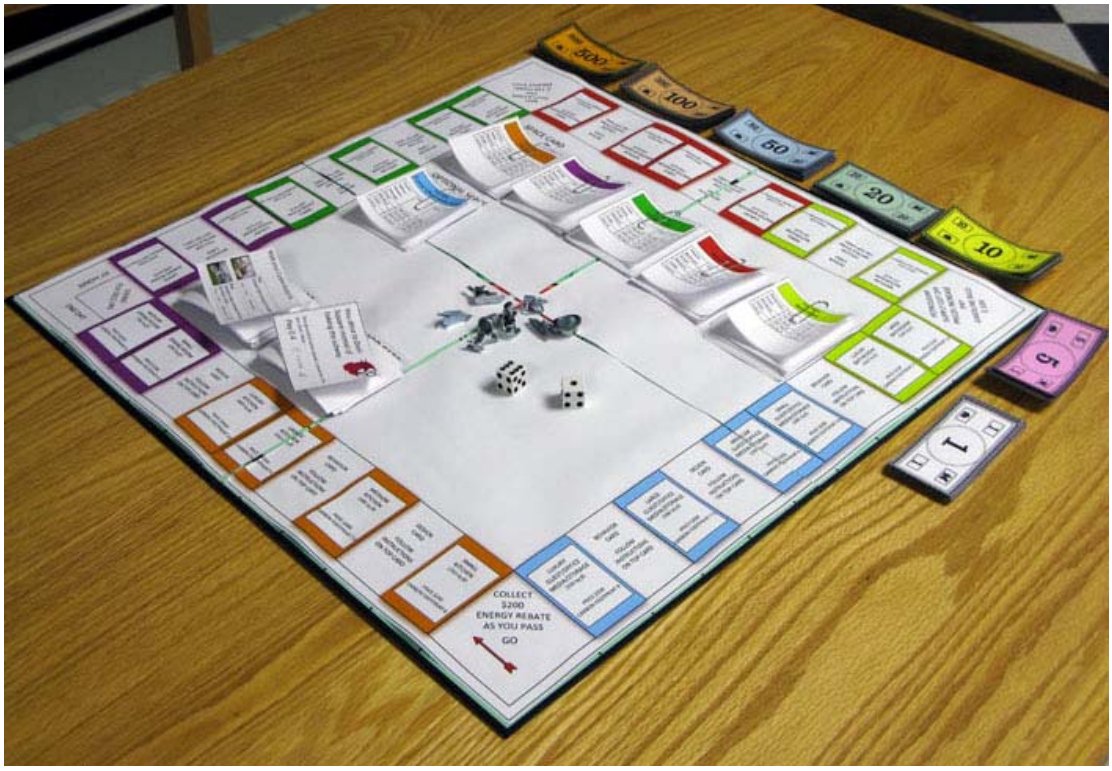


Figure 5.1-2 Prototype 2: Paper Game interface

5.1.2 Game Components

Purpose：

This game intends to explore attitudes toward energy-saving and create awareness to sustainability. It prompts players to re-evaluate and increasingly change their behavior during their design and living simulation.

Goals：

You will start with a budget, and make design and decisions to lower the Carbon Footprint as you design your home. The goal is to complete at least 5 required spaces and reduce CF as fast as you can. Game ends when the first player runs out of money, and who gets the lowest CF wins *[Fig 5.1-3].*

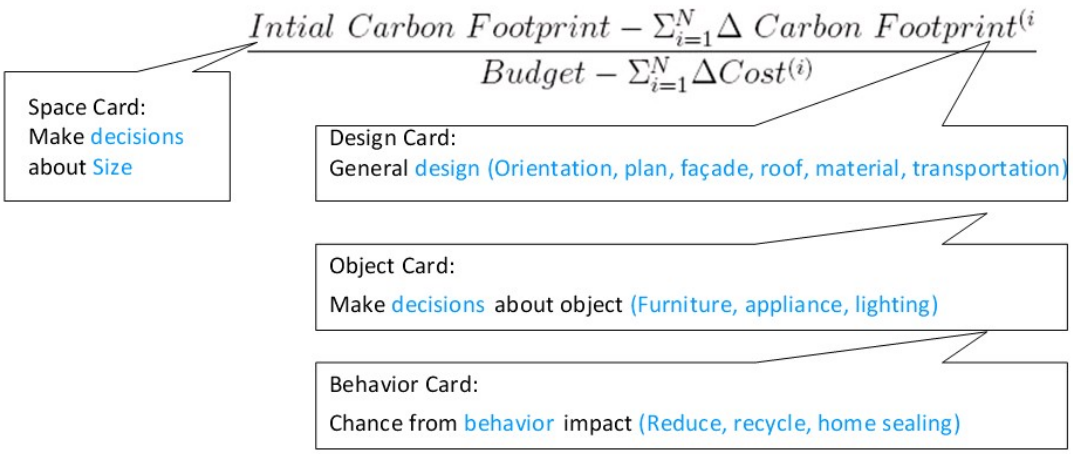


Figure 5.1-3 Carbon Footprint equation

Setting:

Number of players: 2

Play time: at least 1.5 hours

Random chance medium: dice rolling, card drawing

Skill required: design, decision-making, trade-off, resource management

Equipments:

- An "*Green Design-Living-Finance*" game board *[Fig 5.1-4]*
- Game Cards w/ Title Deed: 28 Space cards, 40 Design cards, 40 Behavior cards, 56 Object cards
- A supply of paper money ($15,140)
- Carbon Footprint & cost sheet

Figure 5.1-4 Prototype2: "Green Design-Living-Finance" game board

Space card *[Fig 5.1-5]*:

These cards determine the home design about space function, size, energy system, and appliance/furniture, including:

- 5 required spaces (*Living, Dining, Kitchen, Bathroom, and Bedroom*)
- 1 optional space (*Guest/Office/Media/ Storage*)
- 4 situations (*energy rebate/ stay at home/pay energy bill/pay gasoline bill*)

Design card *[Fig 5.1-6]*:

- These cards have information about how to design a house based on energy efficiency and friendly environment.

Behavior card *[Fig 5.1-7]*:

- Follow the instructions on the behavior card, in many cases, they are like chance card with positive or negative result from your behavior.

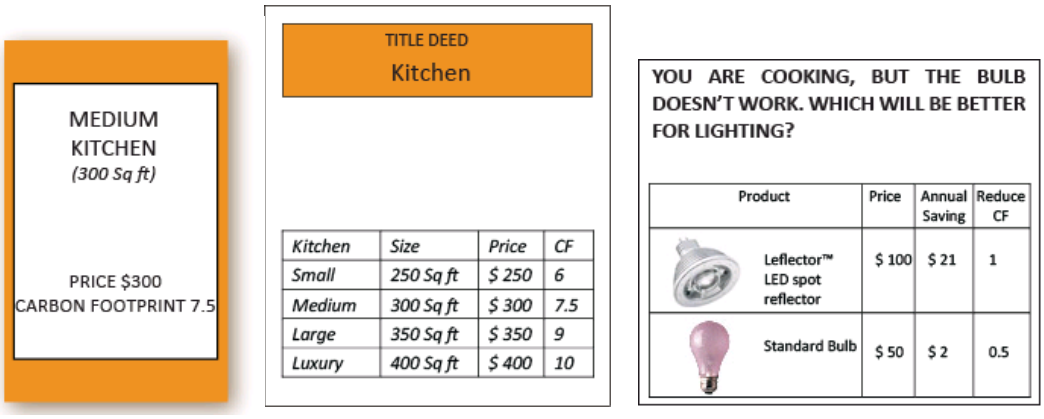


Figure 5.1-5 Space cards

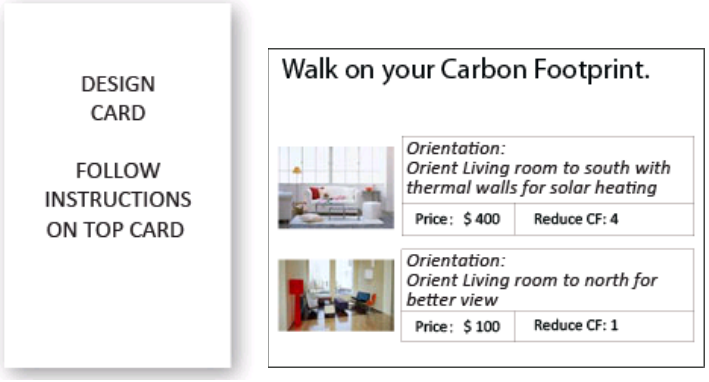


Figure 5.1-6 Design cards

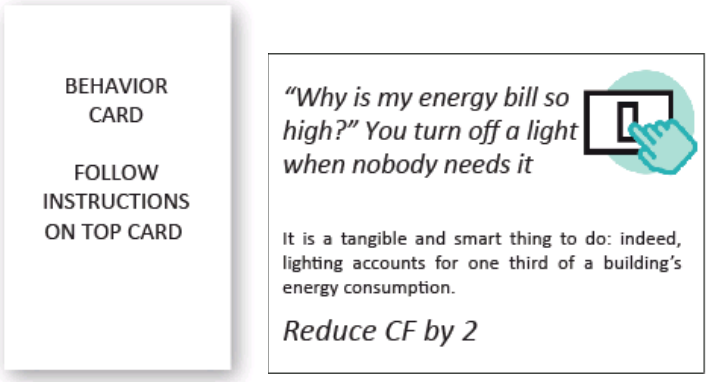


Figure 5.1-7 Behavior cards

Use Cases *[Fig 5.1-8]*:

UC1 Enter Player Info
UC2 Move
UC3 Pass "GO"
UC4 Stay at Home
UC5 Pay gasoline bill
UC6 Pay energy bill
UC7 Space/Object Card
UC8 Design Card/Behavior Card
UC9 Get out of Home

UC10 Roll Dice
UC11 Switch Turn
UC12 View Info

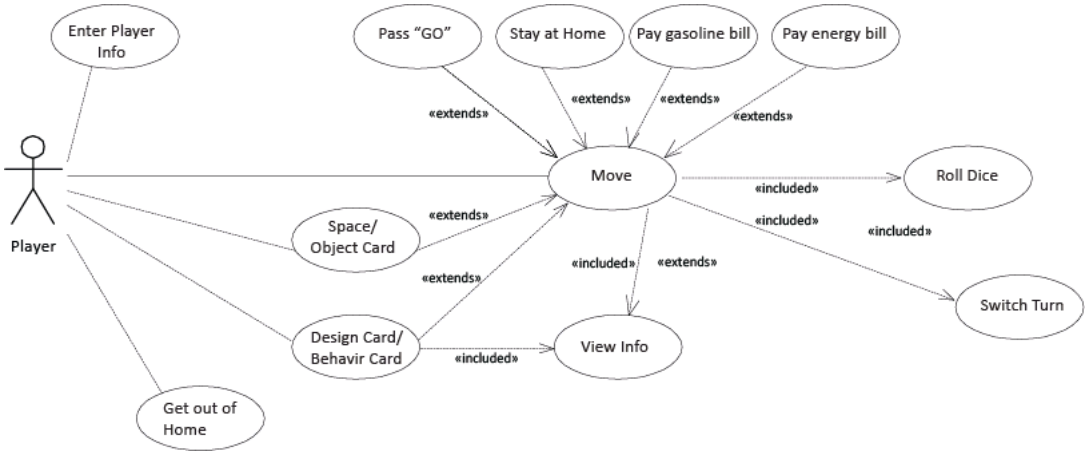


Figure 5.1-8 Use Case Diagram

Flow of Events:

UC1 Enter Player Info

- Set up,
    - Put the game cards face down on their allotted spaces on the board.
    - Player chooses one token to represent himself while traveling around the board.
    - Select a banker. Each player is given $15,140 as initial budget (20 each of $100's and $500's, 30 $50's; 50 $20's; 40 each of $10's, $5's and $1's) and Carbon Footprint is 0. All remaining money goes to the Bank.

UC2 Move

- Turn-based,
    - Movement is based on the player's dice roll [UC10]

UC3 Pass "GO"

- All players receive $200 when passing GO (Energy rebate).

UC4 Stay at Home

- Land on "Stay at Home" or choose "Go to Stay at Home' card,
    - Swine flu occurs, Stay at Home for one time

UC5 Pay gasoline bill

- Petroleum supply cut off prices increase pay gasoline bills &100

UC6 Pay energy bill

- Bad insulation pay &150 home energy bills

UC7 Space/Object Card

- Lands on a color-coded space,
    - Buy it (Carbon Footprint increases) or not
    - When you have the space, reduce Carbon Footprint by choosing objects (Appliances/ Furniture/ Sustainable Product/ Sustainable Solution) on certain space card

UC8 Design Card/Behavior Card

- Land on design card,
    - Draw the top card from that pile, make design decisions.
- Land on behavior card,
    - Draw the top card from that pile; follow the negative or positive behavior impact.

UC9 Get out of Home

- “Get Out of Home Free” card
- Purchasing the “Get Out of Home Free” card from another player
- Paying a fine of $50 before you roll the dice

UC10 Roll Dice

- It is the player’s turn, roll dice.

UC11 Switch Turn

- The player’s turn ends.
- Update your score sheet if the card you get changes your Carbon Credit.

UC12 View Info

- The player can see the status and attributes of cards.

5.2 Learning by Playing: Step by Step

Scenario:

Jack and Jane is one young couple. They love playing games, and like everyone else, they seem to live in the web browser. That's where they work, check email, chat with friends, and go shopping.

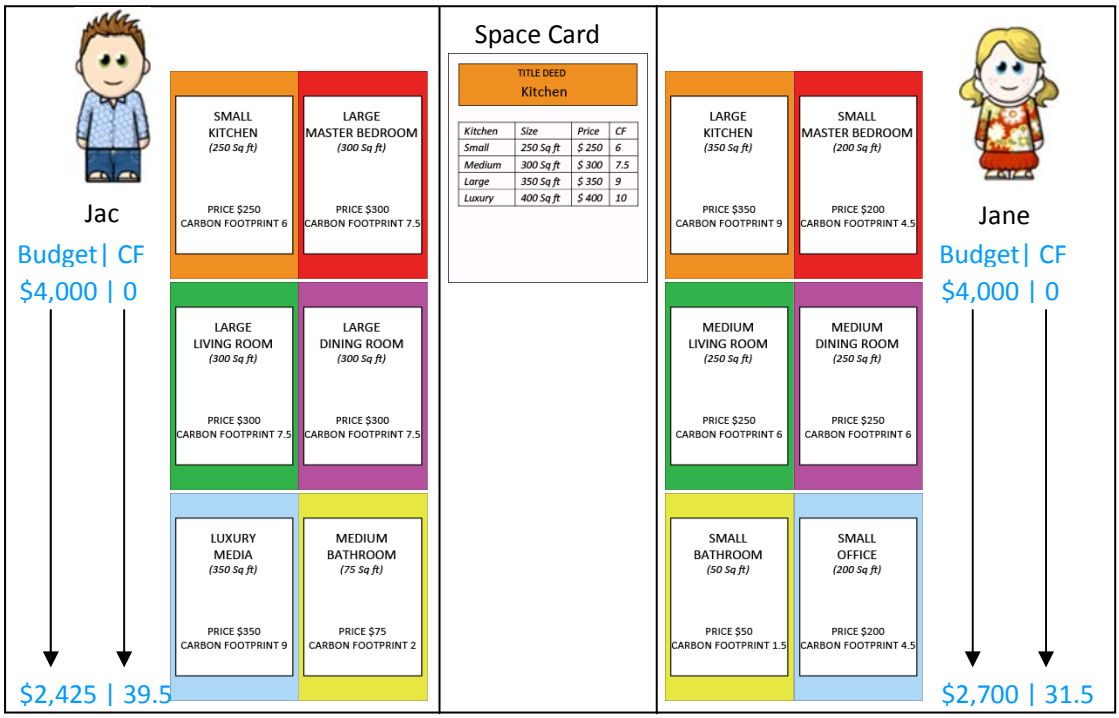
Currently they decide to buy a house. So they are searching online the largest commodity they will ever purchase in their lifetime.

After doing some research, they figure out the trends are towards Green Building. They want to go GREEN as well. So they log on a web site called *www.designyourgreenhome.com*, and found the BIM game there.

So instead of buying home, they decide to play the game first.

Sample of Steps: Space Card

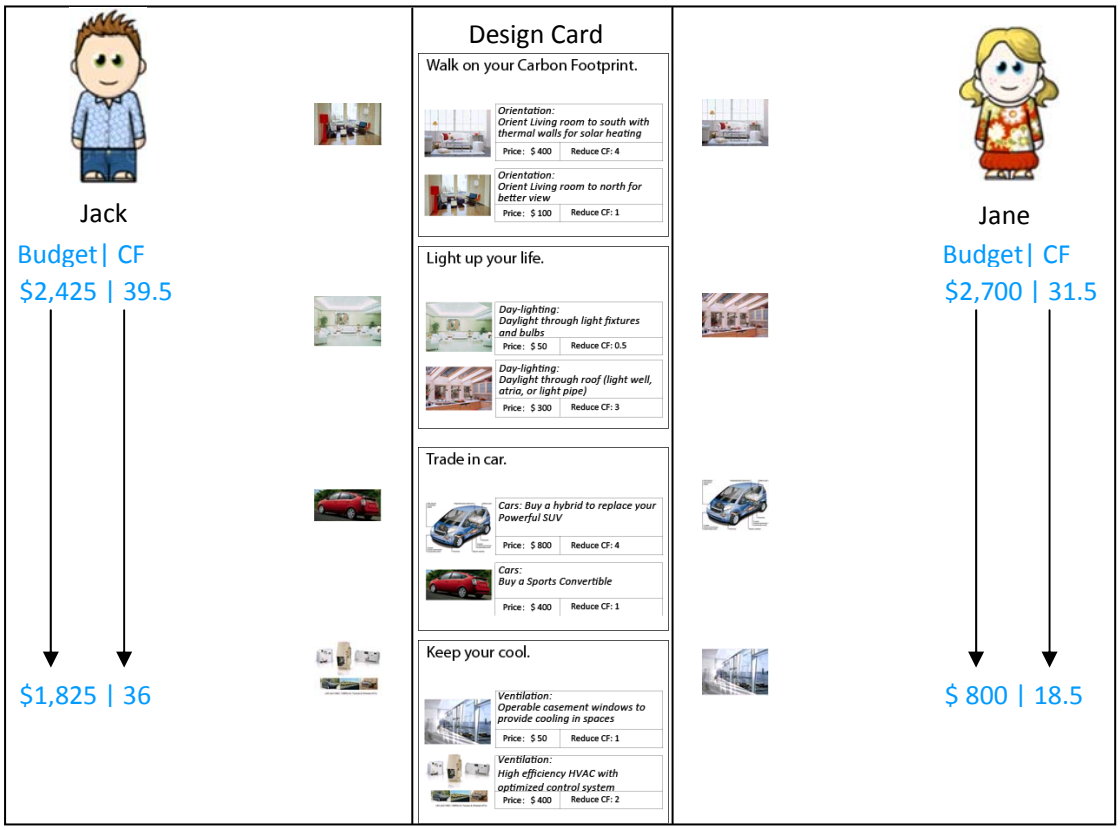
When they first land on the Space Card, they need to make design decisions about whether they need the space and the size of the space. They have to choose from 5 required spaces and 4 optional spaces. Each space has 4 types of size, with different Carbon Footprint.



Learning:
Small space is more efficient with less Carbon Footprint

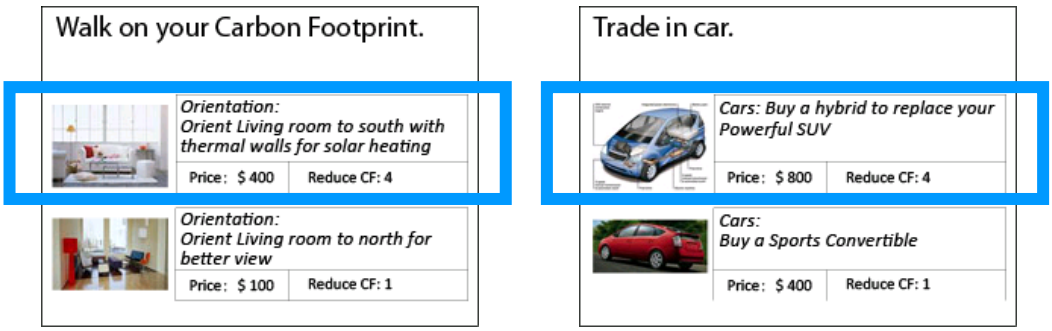
Sample of Steps: Design Card

When they land on the Design Card, they draw the top card from the pile and make design decisions like orientation, plan, façade, roof, material, etc. Choices are not equally good, and there are not obviously good ones. They need to make trade-off between the cost and the Carbon Footprint the design reduced.



Learning:

Orient to south gains more sun light, Daylight is better than electrical lighting, Hybrid car cuts emission, HVAC uses more energy.

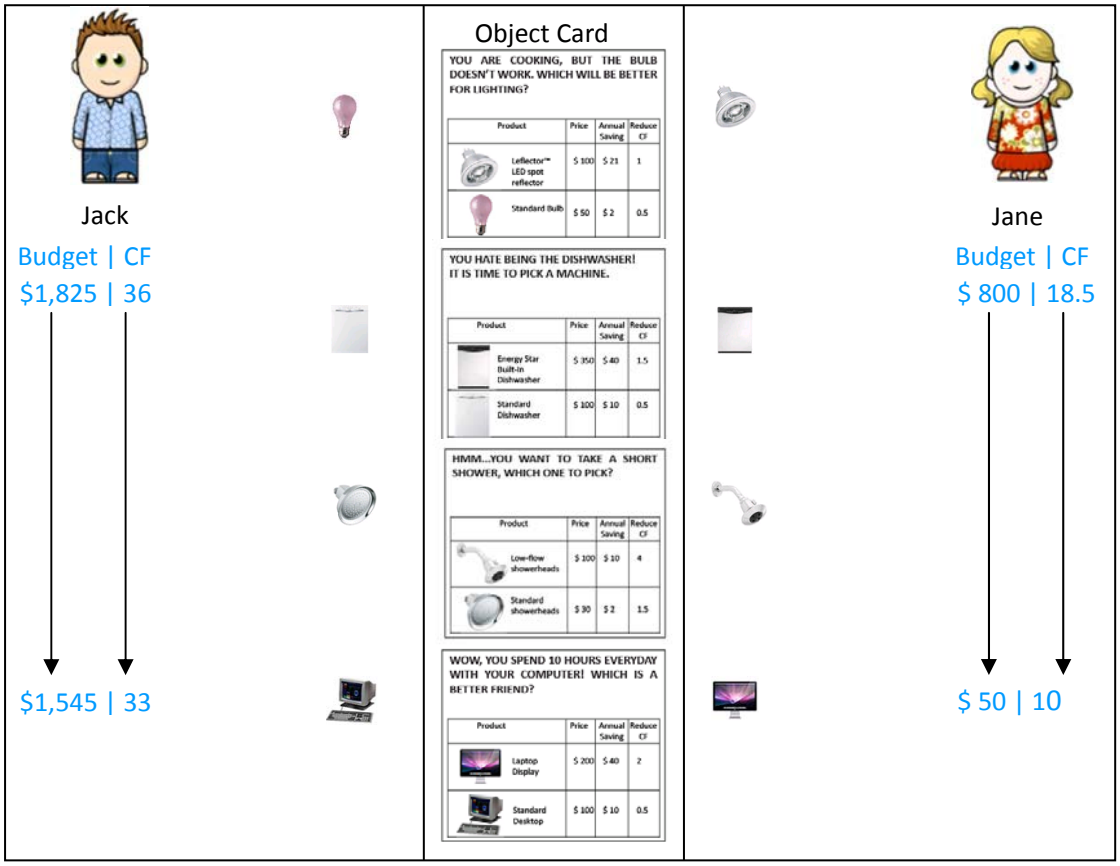


Compare Carbon Cost Ratio (CCR):

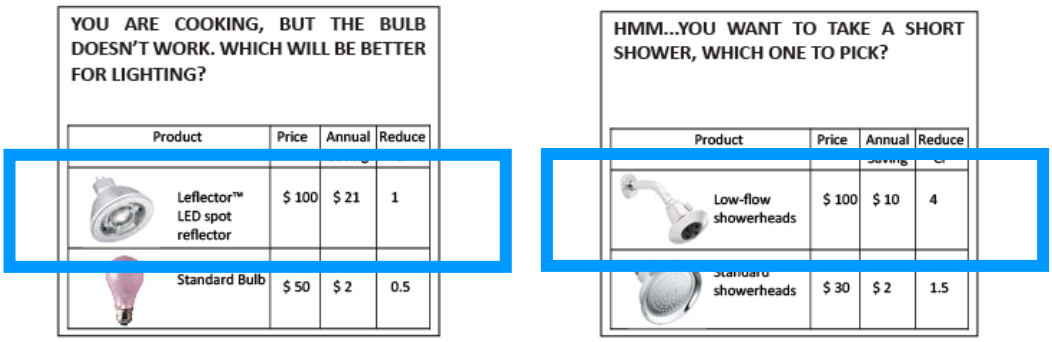
They both reduce Carbon Footprint by 4, but CCR of Orientation is 4/$400, while CCR of Hybrid Car is 4/$800, obviously Orientation is a better deal.

Sample of Steps: Object Card

When they land on the space card, if they already have the space, they make decisions about the object in the space. Example objects are furniture, appliances and lighting. They need to make decisions between similar product and reduce Carbon Footprint within the budget.



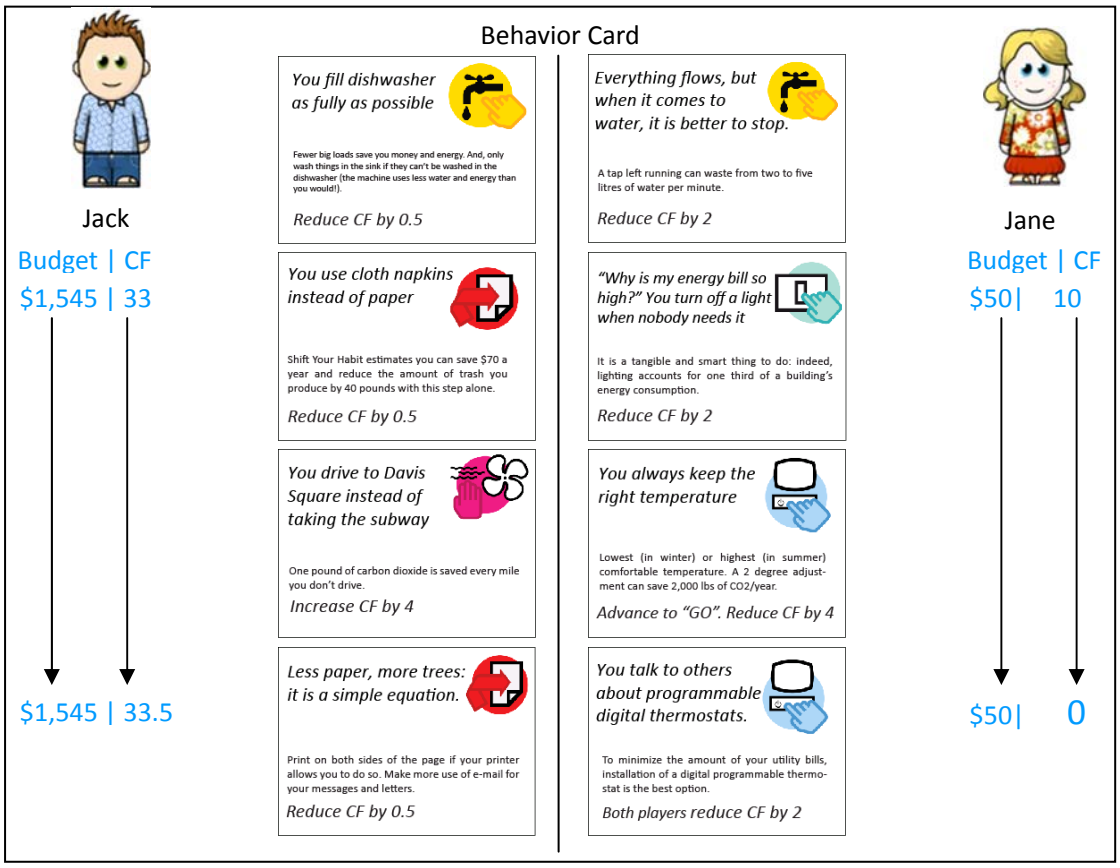
Learning:
LED is expensive, but reduces more CF and saves more in the long turn.
Energy Star@ uses less energy, and last longer than standard one.
Low-flow is a better deal to save water.



Compare Carbon Cost Ratio:
They both cost $100, but CCR of LED is 1/$100, while CCR of Low-flow showerhead is 4/$100, obviously Low-flow showerhead is a better deal.

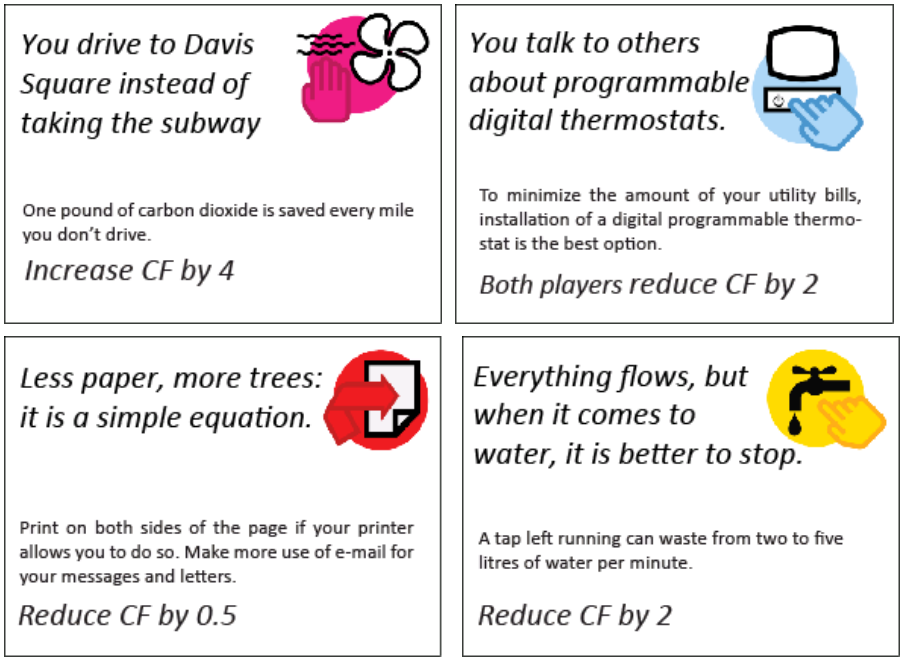
Sample of Steps: Behavior Card

When they land on the Behavior Card, they also draw the card from the top pile. This card is like chance card, people will see the behavior's impact with Carbon Footprint change.



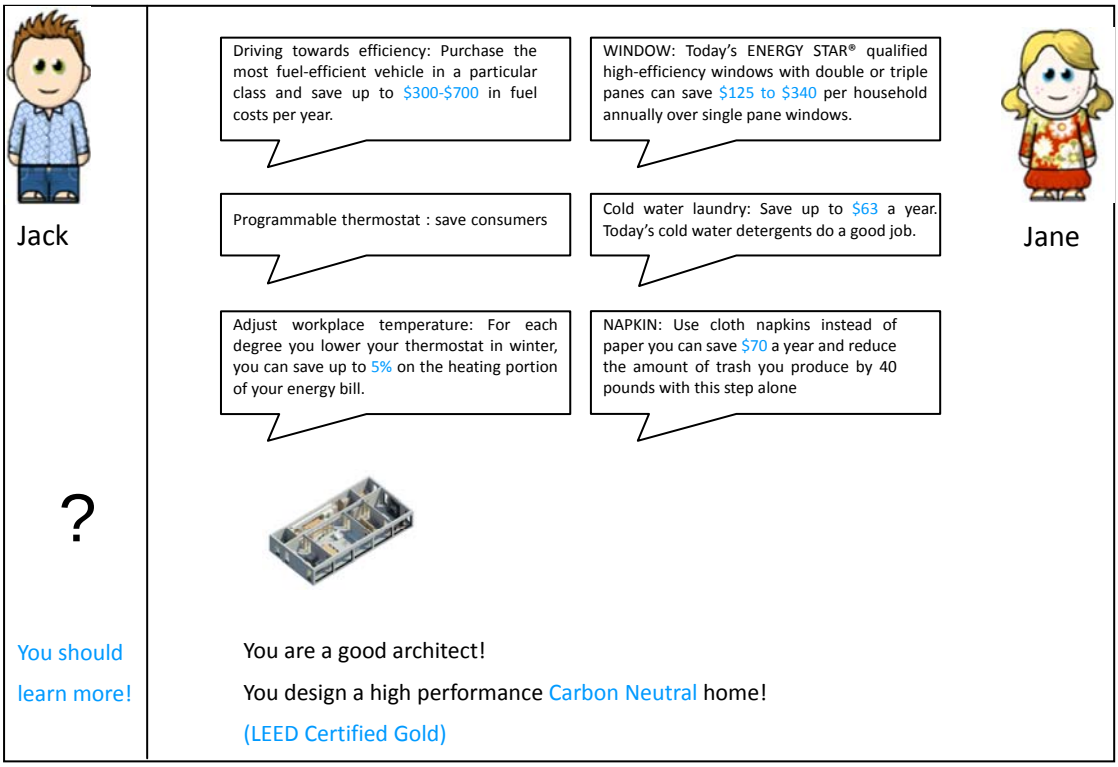
Learning:

Understand the Impacts of Your good or bad behavior



Sample of result:

So finally Jack has a bad design, and get the result “You should learn more!’ While Jane make good decisions along the way and get a high performance Carbon neutral home.



Impact:

It is estimated by the DOE that average household energy cost is **$4,000** in the States.

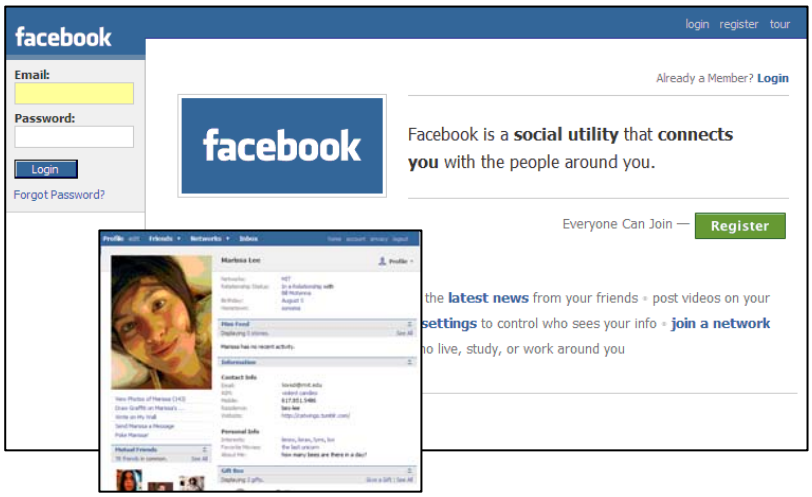
If you could only do 6 steps as Jane designs her home as above, you can simply reduce the cost to **$3,000**.

The BIG number:

If all our nation’s households did the same, we’d save as much energy as is consumed by some **38 million** cars in one year.

Final Output:

Finally, players can publish design on Facebook (200 million user, Search & add friends, Browse common interests, Customizable pages, List music, clubs, activities)



By bring the community and internet together, they can virtually live in the designed home, connect with friends to play, socialize, and share your energy saving methods.

They can also earn Virtual Dollars by encouraging grow more trees, change transportation habit, monitor the energy consumption of home and community.

5.3 Game Reflection

Certain choices may be notable, with better CCR (Carbon Cost Ratio) or ROI (Return On Investment). Other sustainable solutions or products may reduce more Carbon Footprint. After playing the game, player must be able to make informed decisions about:

- Which home system get less Carbon Footprint
- If you play the game again, which combination of choices will you make about the spaces and products
- How many energy-saving tips have you learned after the game, how do you think that can influence your behavior in the real life

5.4 Online Community

BIM game is set up in the web-based environment, where the player can have virtual communication with other players. After the game, they can publish it on certain Social network like Facebook, Myspace, blogs, ect. Interactive communities often develop around mainstream games with or without developers' encouragement, as enthusiasts create websites, discussion boards and other communication environments to exchange information, experiences and even resources related to a game.[82]

Sustainable is not a single effort. It is achieved by the community at large. Players are expected to become aware of the advantages of community. Players choose, from a range of suggested practices, those they believe will best suit a given scenario and will steer their communities toward sustainable practices. [83] Games should augment innovation, responsibility and much more.

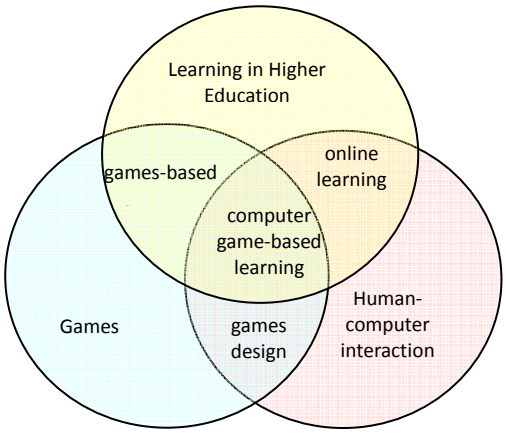


Figure 5.4-1 Learning in a larger community[84]

82 John Kirriemuir, Ceangal, Literature Review in Games and Learning
83 Material & Construction Cost
84 Katrina Baker, Early Years Team, "Play Based Learning"

Chapter 6

Game Playing and Evaluation

6.1 Scenario of Game Playing

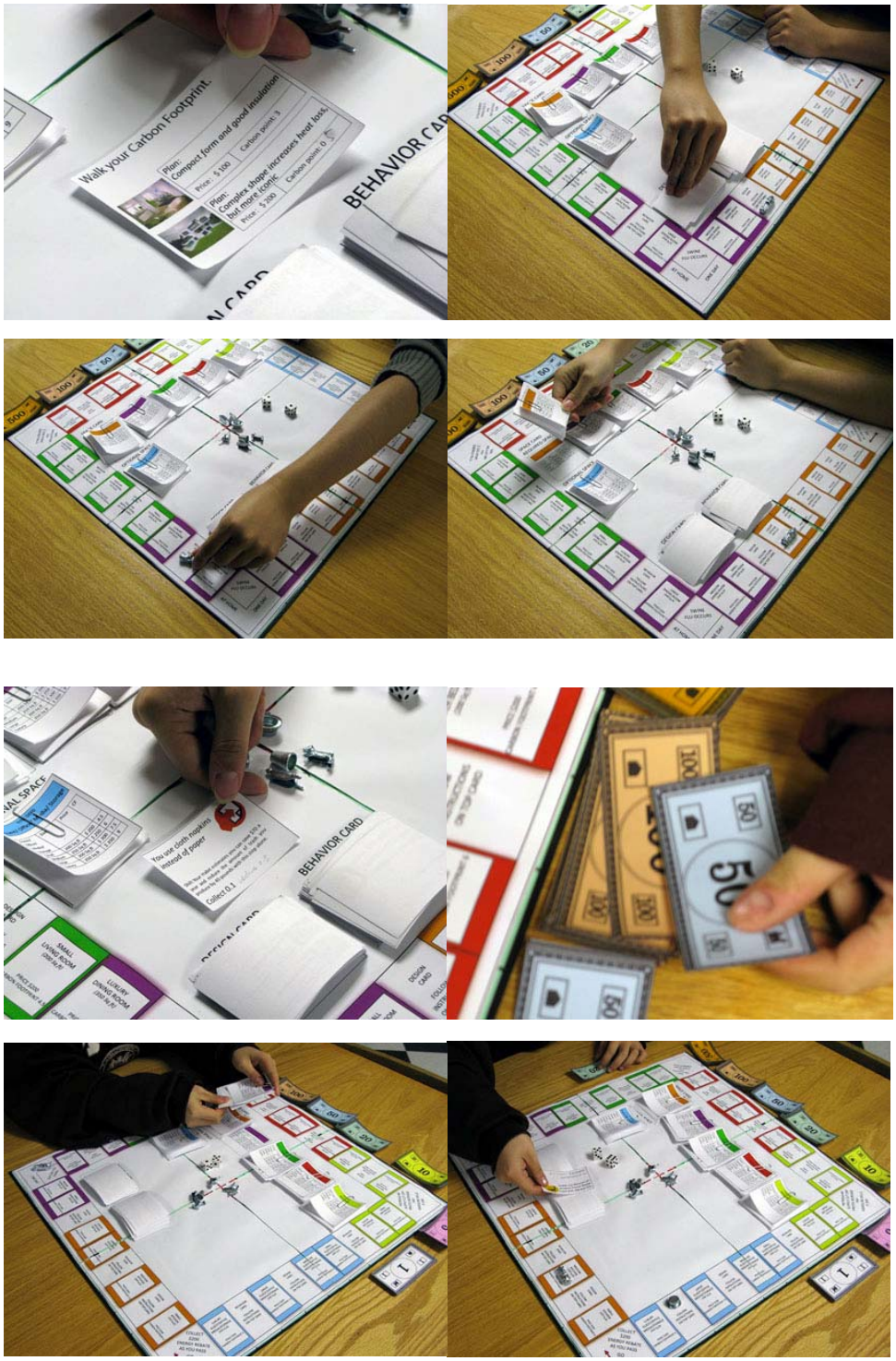


Figure 6.1-1 Photos of participates

6.2 Survey by Intended Users

In order to obtain feedback of the game design, I use the paper-based prototype to test whether the game is easy to understand and playable, the educational value and the effective of the interface.

The four participants in the experiment were all students from MIT who had no experience with architectural design. First, I give them a 5 min explanation about how the game works, then it takes about 5 min practice session. Then the two participants play the game. Second, I take down some oral and written responses from the players and also observe their playing at the same time. Third, I give them questionnaire to see their understanding about energy issue.

6.2.1 Survey Result

The questionnaire involves 3 parts: 1) familiarity with computer and games survey, 2) energy checklist *[Fig 6.2-1]*, 3) game and interface survey *[Fig 6.2-2]*. The category of energy checklist is from "Already in place", "Household goal", to "Date achieved", evaluation of the interface is from "very agreeable" to "very disagreeable".

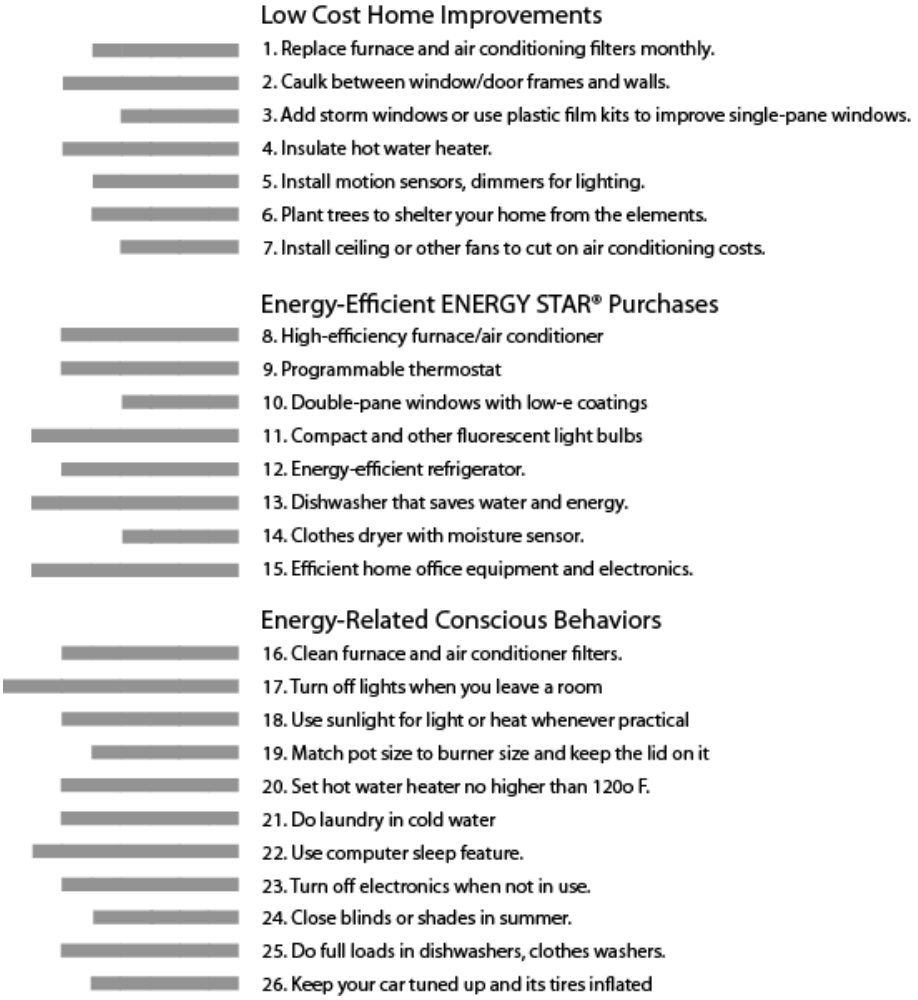


Figure 6.2-1 Energy Checklist survey

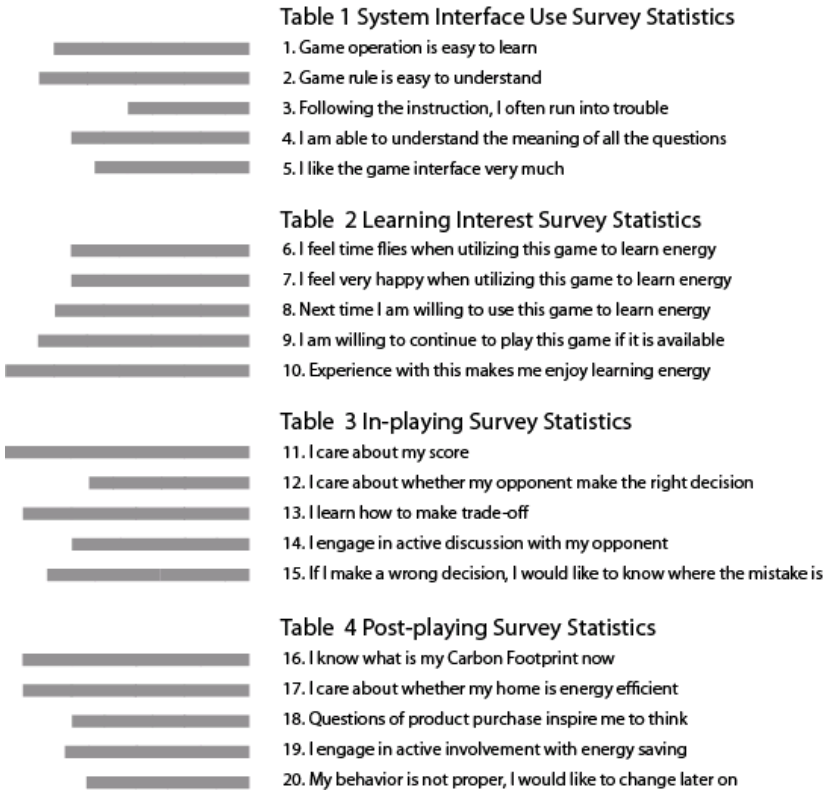


Figure 6.2-2 Game and interface survey

6.2.2 Survey Discussion

The game itself gets a positive response, it helps players to uncover their preference and remember the energy tips. I found the game works well for the simple rules, and participants have no difficulty playing the game and are all focused during their playing. But I also found people's little knowledge about energy. Despite the extensive coverage of energy problems, most people still have little awareness for this topic.

In game feedback:
One important observation is, I was kept on answering the terms and vocabularies. All of them said there are some new concepts they have never exposed before. Some of the terms are easy to explain, like Carbon Offset, Energy Star@, compact plan, and they think they learn from it. But others like the size of home and details of the window; it is hard for some of them to think through when they make decisions.
After several rounds during the playing, one problem exits. They all figure out small space is better, so they finally choose small spaces and don't care about the final result since it doesn't relate directly to what they get. Since the paper-prototype doesn't have visualization, they only care about the numbers on the card.

Post-game feedback:
They want to have visualization.
They care more about the energy-saving tips from behavior card, healthy interior, and energy efficient appliances from object card.

Most of them said they get a strong sense now saving energy is not only about recycling, they saw more aspects about it.
They are influence by me more, since none of their friends are doing energy education and especially with interactive games.

One of the participants is a little skeptical about the game to transfer “serious” skills to people. They have no intention to buy house or design homes their own. But they now have a little judgment about high performance home and they are more interested in how to reduce the energy bills. One even said it might work for his renting house off-campus.

When I talk with them about the web-based one, one of them said the game would work better in certain kind of context. Since the game takes some time and most of people are busy, it would be like “work” after some time, and seems simpler compare with commercial video game. So it would work better in classroom setting, or target at people who really want to design homes. He also suggested to make the game simpler like the game on Facebook, to take about less than 1 min but covers all the energy issue. But they all like the idea to design homes on Facebook, educate community and monitor energy.

Limitation of the survey:
It only tests 4 participates and they are all students. Next step work is to test the game within different ages and profession of people, especially who really have the intention to buy or design their home.

Chapter 7

Conclusion

7.1 Thesis Achievements

My thesis achievement is to design a learning tool to educate non-experts energy-related design and living. This research examines the potential of game education and develops an immersive learning environment that supports energy education activities. Through learning by playing, it is able to create a deep-learning environment and also add emotion to the problem-solving process.

During the background research, first I study the current sustainable trend and also compare the contemporary housing industry with other industries. From these studies, I found out the demands towards high performance low energy home and the importance to educate consumer about energy-related design and decision-making. And then I propose a new model to involve consumers participate in the home design process and educate them about energy. In addition, I look for the media that can smoothly enable consumer to learn, finally I propose a “serious game” to allow homeowners explore their needs and access to powerful ideas in home design.

From these researches, I develop a BIM game which is based on BIM and E-learning game. Because BIM can enable Open Source and calculate Carbon Footprint, all the information can translate to the game, so the consumer can have immediate feedback about their decisions.

In order to test the game education, I invite some non-experts to play. I use the paper-based prototype to test the effectiveness of the game. Before the game, I give them a questionnaire and after the game I give them the questionnaire again to see what they gain during the short time. I also video-tape the playing process, and make records about player’s talking and questions. Finally I also test with them about the user-friendly of the web-based interface.

These tests show that the proposed learning tool can help them raise the awareness of energy-saving and bridge the gap between awareness and behavior change. So the contribution of my work is to explore the use of new educational media to support creative learning and decision-making.

7.2 The Role of the Architect

Consumer participative design can change the supply chain of the design profession. BIM is also a powerful toolkit that constantly changes the building process. By utilizing BIM and game, it can assess what the consumer values most and also teach the consumer about energy-related design and living. By trying to identify design solutions and products the consumer decides, architect can understand more about client needs and finish the design.

7.3 Future Work

Toys for building or assembling physical models—have historically played a powerful educational role in children's lives.[85] By embedding electronics in construction kits we can enable a computer to respond to manipulations of the pieces. With a little imagination these 3D construction kit can be mapped to a problem space to create a richer and more intuitive interaction than assigning meaning to mouse clicks and key combinations.[86]

Tangible interface could be the next step to enable learning design through making things. Game with tangible interface is different from the conventional GUI, it uses tangible object to transfer the digital information. By integrating construction kits with computation, the educational power and expressiveness of these kits can be greatly increased.[87] In the practices of design tool-making and design education, they could encourage the consumer to create artifacts and envision possibilities of design through the physical interface.

85 CoDe Lab Open House, Computationally Enhanced Construction Kits and Craft

86 CoDe Lab Open House, A Computationally Enhanced Construction Kit for Building Rich 3D Interfaces

87 CoDe Lab Open House, Computationally Enhanced Construction Kits and Craft

Appendices 1:

System Detail

Design Card:

Walk on your Carbon Footprint.

Orientation:
Orient Living room to south with thermal walls for solar heating

Price: $ 400 | Carbon point: 4

Orientation:
Orient Living room to north for better view

Price: $ 100 | Carbon point: 1

Walk on your Carbon Footprint.

Material:
Solar façade is good to trap the sun's heat.

Price: $ 100 | Carbon point: 3

Material:
Glass houses let lots of sun in. It'd be like living in a green house.

Price: $ 50 | Carbon point: 1

Walk on your Carbon Footprint.

Plan:
Compact form and good insulation

Price: $ 100 | Carbon point: 3

Plan:
Complex shape increases heat loss, but more iconic

Price: $ 200 | Carbon point: 0.5

Walk on your Carbon Footprint.

Roof: Green roofs are great for keeping heat in the home. Plus they attract wildlife into your house.

Price: $ 400 | Carbon point: 3

Roof:
Regular roof

Price: $ 100 | Carbon point: 1

Walk on your Carbon Footprint.

Roof:
Building integrated photovoltaic system (BIPV)

Price: $ 800 | Carbon point: 6

Roof:
Regular roof

Price: $ 100 | Carbon point: 1

Reinstall Windows free.

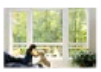
Window:
Standard window w/o overhang (require AC in summer)

Price: $ 10 | Carbon point: 0.5

Window:
Overhangs in some areas to minimize solar gain in the summer

Price: $ 50 | Carbon point: 2

Reinstall Windows free.



Glazing Amount:
Low-e glazing (+ 25%)

Price: $ 50 | Carbon point: 1

Glazing Amount:
Optimizing daylight through fenestration (light shelves, louvers) -25%

Price: $ 100 | Carbon point: 2

Customize your home.

Kitchen:
U-shape kitchen

Price: $ 50 | Carbon point: 1

Kitchen:
L-shape kitchen with dinning area

Price: $ 50 | Carbon point: 1

Customize your home.

Kitchen:
One side kitchen

Price: $ 50 | Carbon point: 1

Kitchen:
Two side kitchen

Price: $ 50 | Carbon point: 1

Customize your home.

Dining Room:
Self-contained dining room between kitchen and living room

Price: $ 50 | Carbon point: 1

Dining Room:
W/ living room on common patio giving good natural lighting

Price: $ 50 | Carbon point: 1

Customize your home.

LDK:
Living room, dining room, kitchen all open to each other.

Price: $ 100 | Carbon point: 1

LDK:
2 storey Large living room for social activity

Price: $ 200 | Carbon point: 2

Customize your home.

Wheelchair Circulation:
Daily activities sitting on the wheel chair, installation of an elevator

Price: $ 100 | Carbon point: 2

Wheelchair Circulation:
Wide entrance area to accommo date wheelchair occupants

Price: $ 50 | Carbon point: 1

Customize your home.

SOHO:
separation of space depends on the user

Price: $ 50 | Carbon point: 1

LOFT:
studio apartment

Price: $ 50 | Carbon point: 1

Customize your home.

Bedroom:
With dressing corridor, adjacent to kid's room

Price: $ 50 | Carbon point: 1

Bedroom:
With dressing room and access to bathroom

Price: $ 50 | Carbon point: 1

Too "Plugged In".

Renewable Energy:
Solar collectors or heat pumps provide energy for hot water.

Price: $ 400 | Carbon point: 4

Renewable Energy:
Wind generators/turbines installed on rooftops to capture wind

Price: $ 200 | Carbon point: 3

Too "Plugged In".

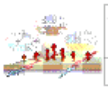
Solar:
Solar pool heating

Price: $ 100 | Carbon point: 2

Solar:
Attached solar house

Price: $ 300 | Carbon point: 3

Too "Plugged In".



Heating & cooling:
Geothermal heating & cooling

Price: $ 400 | Carbon point: 3

Heating & cooling:
HVAC heating & cooling

Price: $ 200 | Carbon point: 1

Too "Plugged In".

Water Energy:
Install a graywater system

Price: $ 400 | Carbon point: 3

Water Energy:
Install a Wastewater Treatment System

Price: $ 600 | Carbon point: 4

Too "Plugged In".

Environment: A drainage plan that concentrate plantings where they will be watered by irrigation, and storm water run-off.

Price: $ 100 | Carbon point: 1

Environment: Native and adapted species, Low-water landscaping and high efficiency irrigation

Price: $ 100 | Carbon point: 1

Light up your life.

Day-lighting:
Daylight through roof (light well, atria, or light pipe)

Price: $ 300 | Carbon point: 3

Day-lighting:
Daylight through light fixtures and bulbs

Price: $ 50 | Carbon point: 0.5

Light up your life.

Day-lighting:
Clerestory & skylight & sun-corridor

Price: $ 200 | Carbon point: 2

Day-lighting:
Reduce light pollution by directing light downward

Price: $ 50 | Carbon point: 1

Light up your life.

Day-lighting:
Low-e glazing

Price: $ 50 | Carbon point: 1

Day-lighting:
Courtyard for Internal Daylight

Price: $ 100 | Carbon point: 3

Is your home leaking energy dollars?

Envelope:
Install a rain screen wall system

Price: $ 100 | Carbon point: 2

Envelope:
Install storm windows if you only have single-pane windows.

Price: $ 50 | Carbon point: 1

Is your home leaking energy dollars?

Envelope:
Seal air leaks and add insulation to the building envelope

Price: $ 100 | Carbon point: 3

Envelope:
Install insulated frames & Low-E glazing

Price: $ 50 | Carbon point: 2

Is your home leaking energy dollars?

Thermal:
Thermal mass + Sun-corridor

Price: $ 150 | Carbon point: 3

Thermal:
wall system with a thermal envelope (insulation layer)

Price: $ 100 | Carbon point: 2

Is your home leaking energy dollars?

Envelope:
Use of high performance glazing designed to maximize insulating levels

Price: $ 200 | Carbon point: 4

Envelope:
wall system with a thermal envelope (insulation layer)

Price: $ 50 | Carbon point: 2

Keep your cool.

Ventilation:
Operable casement windows to provide cooling in spaces

Price: $ 50 | Carbon point: 1

Ventilation:
High efficiency HVAC with optimized control system

Price: $ 400 | Carbon point: 2

Keep your cool.

Landscaping: Use of trees on west or south side to help even out energy requirements within the buildings.

Price: $ 100 | Carbon point: 3

Landscaping:
Trellis for vegetation

Price: $ 50 | Carbon point: 2

Keep your cool.

Ventilation:
Overhangs aids cross ventilation

Price: $ 150 | Carbon point: 3

Ventilation:
Screen with adjustable blade

Price: $ 50 | Carbon point: 2

Keep your cool.

Ventilation:
Single-sided ventilation, no ventilation of interior space

Price: $ 50 | Carbon point: 1

Ventilation:
Mixed cross, single-sided local, and stack ventilation

Price: $ 100 | Carbon point: 3

You've been elected Green Community Officer.

Community: Design for walking & cycling, pedestrian access to neighborhood service within 1/2mi

Price: $ 150 | Carbon point: 4

Community: Design for outdoor gathering places

Price: $ 100 | Carbon point: 3

Make Upgrades For All Your Appliances.

Sensor:
Occupancy sensors to control lights in seldom used rooms, auto night shut-off

Price: $ 50 | Carbon point: 2

Sensor:
Daylighting sensors with appropriate task lighting is often very effective.

Price: $ 25 | Carbon point: 1

Make Upgrades For All Your Appliances.

Materials:
Low-Emitting materials

Price: $ 50 | Carbon point: 1

Materials:
Renewable, Recyclable, Recycled Content, Reused

Price: $ 100 | Carbon point: 2

Trade in car.

Cars:
Buy a biodiesel to replace your Deluxe Sedan

Price: $ 600 | Carbon point: 4

Cars:
Buy a Mid Size Sedan

Price: $ 200 | Carbon point: 1

Trade in car.

Cars: Buy a hybrid to replace your Powerful SUV: Hybrids cut your emissions by as much as 50%.

Price: $ 800 | Carbon point: 4

Cars:
Buy a Sports Convertible

Price: $ 400 | Carbon point: 1

Trade in car.

Cars:
Purchase carbon offsets for your first car

Price: $ 50 | Carbon point: 4

Cars:
Purchase carbon offsets for your two cars

Price: $ 200 | Carbon point: 6

Trade in car.

Public Transportation:
Passengers do not travel in their own vehicles.

Price: $ 50 | Carbon point: 3

Cars:
Automobile for individuals and businesses.

Price: $ 100 | Carbon point: 1

Trade in car.

Cars:
Automobile for individuals and businesses.

Price: $ 50 | Carbon point: 1

Bicycles:
A great, sustainable alternative.

Price: $ 100 | Carbon point: 3

Behavior Card:

"Why is my energy bill so high?" You turn off a light when nobody needs it

It is a tangible and smart thing to do: indeed, lighting accounts for one third of a building's energy consumption.

Reduce CF by 2

You forget to unplug TV after the comic show.

Even when they are turned off, appliances still use energy while they are plugged in.

Increase CF by 2

You don't have a backyard, so you use the dryer Instead of hang out laundry

You can get an inexpensive drying rack or camping clothesline for indoors. Each load of laundry you hang out is energy saved and money in your pocket.

Increase CF by 2

"Why is my energy bill so high?" You decide to replace regular light bulbs with CFL

Compact Fluorescent Lamps (CFL) lasts about 10 times longer than regular lighting and use about 1/4 the energy.

Reduce CF by 2

You cover water when heating it so it heats faster

One of those free and SUPER easy Energy Saving Tips!

Reduce CF by 1

You never shut off your computer, printer, and photocopier

A computer uses up to 300 watts per hour when it is on. Do not copy one page at a time but all in one go to reduce energy consumption

Increase CF by 2

You use energy saving air dry on the dishwasher

The dishes will still dry nicely without the heat and you will save energy.

Reduce CF by 1

You enable the sleep mode when you leave the computer

Turn the computer off when you aren't using it. Screen savers use energy.

Your habit matures. Reduce CF by 2

Read more, watch TV less

The "off" setting of most electronic equipment is actually a "standby" or "idling" mode. The energy of standby is enough to power an entire home for two months. The solution? Unplug anything that isn't being used.

Your habit matures. Reduce CF by 2

After visiting your friend's new home, you decide to purchase green powers

Generally, green power adds $2 to $3 a month to your utility bill while helping to combat global climate change and America's dependence on foreign oil.

Advance to "GO". Reduce CF by 4

Your kids forget to turn off entertainment devices (TV, game, etc.)

This is one of those Energy Saving Tips we all know about but is sometimes hard to get the kids to remember.

Increase CF by 2

You use smaller heating appliances for small meals instead of the oven

Instead of heating up the whole oven, use a toaster oven or microwave if you have them. They will use less energy.

Reduce CF by 2

You bring your own bags to grocery store

Bring your own bags to the grocery store & recycle plastic bags at the grocery store (Whole Foods and Jewel Osco have places to do so)

Reduce CF by 1

Less paper, more trees: it is a simple equation.

Print on both sides of the page if your printer allows you to do so. Make more use of e-mail for your messages and letters.

Reduce CF by 0.5

You get books from the public library instead of buying them new

Your habit matures. Reduce CF by 2

You use cloth napkins instead of paper

Shift Your Habit estimates you can save $70 a year and reduce the amount of trash you produce by 40 pounds with this step alone.

Reduce CF by 0.5

You consider buying second-hand items at Craigslist

Buying second-hand items at resale shops and sites like Freecycle (It's a grassroots and entirely nonprofit movement of people who are giving stuff for free in their own towns)

Your habit matures. Reduce CF by 2

You drive to Davis Square instead of taking the subway

One pound of carbon dioxide is saved every mile you don't drive.

Increase CF by 4

You check tires before you drive to work

Properly inflated tires can improve gas mileage by more than 3%.

Energy rebate. Reduce CF by 2

You always use hot water

It takes a lot of energy to heat water.

Increase CF by 1

You fiill the sink when doing dishes instead of running the water

This uses 3 times less water.

Reduce CF by 1

Everything flows, but when it comes to water, it is better to stop.

A tap left running can waste from two to five litres of water per minute.

Reduce CF by 2

You turn off water when brushing teeth and shaving

Take shorter showers instead of baths and only run full dishwashers and washing machines.

Reduce CF by 1

You report leaks to the housing facility

A leaking faucet can waste 1500 gallons of water/year.

Advance to "GO". Reduce CF by 4

You can feel heat when you touch water heater, you consider buying a water heater blanket

A blanket can help insulate it.

Reduce CF by 1

You never clean the lint trap when you use the dryer

It doesn't matter if you clean it before or after you use the dryer as long as you do it every time. The dryer will run more efficiently with a clean lint trap.

Increase CF by 1

You flush toilets unnecessarily or use it as a wastebasket

Each flush uses up to 5 gallons of water.

You need to change habit. Increase CF by 1

You fill dishwasher as fully as possible

Fewer big loads save you money and energy. And, only wash things in the sink if they can't be washed in the dishwasher (the machine uses less water and energy than you would!).

Reduce CF by 0.5

You notice a poor sealing on the refrigerator door

Close the door on a piece of paper then gently, try to pull the paper out. If easily, the seal is not tight, cold air could be leaking out and you could be wasting energy and money. If the paper stays put, the seal is good. You are assessed for repairs.

You are assessed for repairs. Reduce CF by 2

You talk to others about programmable digital thermostats.

To minimize the amount of your utility bills, installation of a digital programmable thermostat is the best option.

Both players reduce CF by 2

You always keep the right temperature

Lowest (in winter) or highest (in summer) comfortable temperature. A 2 degree adjustment can save 2,000 lbs of CO2/year.

Advance to "GO". Reduce CF by 4

You keep the heat out when it's sunny and hot

Window Coverings can help block the sun's heat so your cooling system won't have to work so hard.

Reduce CF by 2

You separate waste into boxes and baskets for paper waste

Do not forget to use special waste bins (for plastics, cans, glass and other materials).

Reduce CF by 2

You buy products with minimal packaging or in bulk

You can save 1,200 lbs of CO2 if you reduce your garbage by 10%.

Reduce CF by 2

Instead of installing a vinyl shower curtain, you hang up a hemp one

It's equally anti-fungal and does not release small amounts of volatile organic compounds every time you take a shower.

Get out of "STAY AT HOME" Free. This card maybe kept until needed or traded.

You have pesticides stored within reach of children.

Many gardeners improperly apply pesticides, putting their families and pets at increased health risk.

Go directly to "STAY AT HOME". Do not pass "GO", do not collect $200

You never use rechargeable batteries

Set aside bins in your green home to separate and collect recyclable materials, including newspapers, white paper, clear and colored glass, plastic water and milk bottles, aluminum, cardboard, batteries and fluorescent light bulbs.

Go directly to "STAY AT HOME". Do not pass "GO", do not collect $200

Choose fragrance-free products, don't pollute your indoor air or mask odors that could alert you to a problem.

Get out of "STAY AT HOME" Free. This card maybe kept until needed or traded.

You buy locally produced items, including produce and other goods

It reduces the amount of fossil fuels, plastic products consumed in the packaging required to transport the things you buy from other parts of the country.

Your habit matures. Reduce CF by 2

You reuse file folders and corrugated boxes

Instead of using grocery stores' disposable plastic or paper bags, bring your own reusable tote bags, which are available for sale at many grocers and other retailers.

Reduce CF by 1

Your harsh kitchen cleanser (linked to all sorts of ailments, pregnancy-disorders) will hurt you, your children, and your pets.

Go directly to "STAY AT HOME". Do not pass "GO", do not collect $200

You can find eco-friendly detergents at any natural grocery store

You can find even many mainstream stores. Just read the labels carefully.

Get out of "STAY AT HOME" Free. This card maybe kept until needed or traded.

Replace Dirty Filters and Coils

Check your refrigerator and furnace every six months and replace when necessary.

Energy rebate. Reduce CF by 2

Finally, you give up on the bottled water

Not only will you protect the environment by cutting back on your consumption of plastic, but you will also save a bundle over the long-term on drinking water costs.

Reduce CF by 2

You only purchase long-lasting products and only what you need

Your habit matures. Reduce CF by 2

Now you are trying a French Press coffee drinker

When using a French Press, you only use energy to heat the water initially because the press itself doesn't use electricity.

Reduce CF by 1

You hold a neighborhood swap party to get rid of items you no longer use

Instead of trucking your old sofa or 1999 Sony T.V. to the dump, find your used furnishings a second home. You can also sell stuff on e-bay or Craigslist or give it away it at a garage sale.

Reduce CF by 2 from the other player

Object Card:

Kitchen:

YOU ARE COOKING, BUT THE BULB DOESN'T WORK. WHICH WILL BE BETTER FOR LIGHTING?

Product	Price	Annual Saving	Reduce CF
 Leflector™ LED spot reflector	$ 100	$ 21	1
 Standard Bulb	$ 50	$ 2	0.5

YOUR SINK LEAKS! WHICH WILL BE BETTER TO PICK?

Product	Price	Annual Saving	Reduce CF
 Flow Control Aerator	$ 100	$ 4	1.5
 Standard Kitchen Swivel Aerator	$ 25	$ 1	0.5

WANT TO ADD INSULATION?

Product	Price	Annual Saving	Reduce CF
 Tube Pipe Insulation	$ 50	$ 4	0.5
No. I don't want to add insulation.	$ 0	$ 0	0

TIME TO CHOOSE A CABINET.

Product	Price	Annual Saving	Reduce CF
 Green Cabinet	$ 200	$ 6	4
 Standard Cabinet	$ 50	$ 1	1.5

CFL OR LED?

Product	Price	Annual Saving	Reduce CF
 compact fluorescent lighting (CFL)	$ 50	$ 1	0.5
 LED lighting	$ 50	$ 1	0.5

BUY AN INSULATING JACKET AND WRAP IT UP!

Product	Price	Annual Saving	Reduce CF
 Ace Water Heater Insulation Jacket	$ 50	$ 6.6	0.5
No. I don't want to add insulation.	$ 0	$ 0	0

COOKING TIME, NEED AN OVEN?

Product	Price	Annual Saving	Reduce CF
 Solar Oven	$ 250	$ 4	2
 Standard Oven	$ 50	$ 2	0.5

WHICH END OPENS?

Product	Price	Annual Saving	Reduce CF
 Eco-Me Home Cleaning Kit	$ 50	$ 0	1
 Trash Bag	$ 10	$ 0	0.5

HMM...WHAT WILL BE BETTER FOR COOKING?

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR CFM Vent Fan	$ 100	$ 0	1
 Standard Ceiling Fan/vent	$ 50	$ 0	0.5

WOW, IT'S A MESS IN HERE!

Product	Price	Annual Saving	Reduce CF
 Composting Supplies	$ 25	$ 0	0.5
I never recycle...	$ 0	$ 0	0

Bathroom:

YOU HATE BEING THE DISHWASHER! IT IS TIME TO PICK A MACHINE.

Product	Price	Annual Saving	Reduce CF
 Energy Star Built-In Dishwasher	$ 350	$ 40	1.5
 Standard Dishwasher	$ 100	$ 10	0.5

HMM...YOU WANT TO TAKE A SHORT SHOWER, WHICH ONE TO PICK?

Product	Price	Annual Saving	Reduce CF
 Low-flow showerheads	$ 100	$ 10	4
 Standard showerheads	$ 30	$ 2	1.5

WOW, IT'S A MESS IN HERE! WHICH IS THE BEST WAY FOR YOU TO CLEAN?

Product	Price	Annual Saving	Reduce CF
 High-efficiency clotheswasher	$ 300	$ 4	1.5
 Standard clotheswasher	$ 100	$ 1	0.5

TIME TO CHOOSE A TOILET.

Product	Price	Annual Saving	Reduce CF
 Dual flush or ultra-efficient toilet	$ 300	$ 7	6
 Standard toilet	$ 100	$ 2	1.5

YOUR SINK LEAKS!

Product	Price	Annual Saving	Reduce CF
 Dual Spray Flow Control Aerator	$ 50	$ 4	1.5
 Standard Sink Faucet	$ 25	$ 1	0.5

YOUR DOOR LEAKS!

Product	Price	Annual Saving	Reduce CF
 Sliding Door Caulk	$ 50	$ 6	1
No. I don't want to insulate...	$ 0	$ 0	0

YOU ARE SICK OF WET CLOTHES; TIME TO GET SOMETHING TO DRY THEM!

Product	Price	Annual Saving	Reduce CF
 Umbrella Outdoor Clothes Dryer	$ 50	$ 16	1
No. I prefer machines...	$ 0	$ 0	0

REPLACE LIGHTS WITH VANITY LIGHTS!

Product	Price	Annual Saving	Reduce CF
 Leflector™ LED spot reflector	$ 100	$ 21	1
 Standard Bulb	$ 50	$ 2	0.5

HMM...WHICH WILL BE BETTER FOR HEATING WATER?

Product	Price	Annual Saving	Reduce CF
 Tankless hot water heater	$ 250	$ 6	2.5
 Standard water heater	$ 150	$ 1	1.5

WANT TO ADD HOME SEALING?

Product	Price	Annual Saving	Reduce CF
 Lap Sealant Caulk Tube	$ 25	$ 2	0.5
No. I don't want to add insulation.	$ 0	$ 0	0

Living room:

IT'S BEEN HOT! HOW TO COOL DOWN A LITTLE BIT?

Product	Price	Annual Saving	Reduce CF
 Energy Star Window Air Conditioner	$ 200	$ 2	1
 Standard AC	$ 100	$ 4	0.5

WOW, YOU SPEND 10 HOURS EVERYDAY WITH YOUR COMPUTER! WHICH IS A BETTER FRIEND?

Product	Price	Annual Saving	Reduce CF
 Laptop Display	$ 200	$ 40	2
 Standard Desktop	$ 100	$ 10	0.5

WANT TO REPLACE FIRE DAMPER?

Product	Price	Annual Saving	Reduce CF
 Fireplace Damper 30"	$ 50	$ 2	1
No. I don't want to replace.	$ 0	$ 0	0

NEED A LIGHT?

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR Light Bulb	$ 100	$ 1	1.5
 Standard Light Bulb	$ 50	$ 4	0.5

WANT TO COMPOST?

Product	Price	Annual Saving	Reduce CF
 Envirocycle Composter	$ 50	$ 0	0.5
No. I don't want to compost...	$ 0	$ 0	0

NEED A LIGHT?

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR Light Fixture	$ 150	$ 21	1.5
 Standard Light Fixture	$ 100	$ 4	1

BELOW ZERO TEMPS!

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR Heater	$ 250	$ 26	2.5
 Standard Heater	$ 150	$ 4	1

INSTALL A PROGRAMMABLE THERMOSTAT!

Product	Price	Annual Saving	Reduce CF
 Install a programmable thermostat	$ 50	$ 28	1.5
No, I don't want to install this...	$ 0	$ 0	0

YOU ARE SICK OF UNPLUGGING; TIME TO BUY A POWER STRIP!

Product	Price	Annual Saving	Reduce CF
 Power Strip	$ 50	$ 4	1
I doubt about this...	$ 0	$ 0	0

LET'S DANCE!

Product	Price	Annual Saving	Reduce CF
 Energy Star 3.0	$ 350	$ 18	4
 Standard Home Theatre	$ 100	$ 2	1

Bedroom:

YOU JUST MOVE IN YOUR NEW HOUSE. TIME TO CHOOSE A BED!

Product	Price	Annual Saving	Reduce CF
 Custom Sustainable Bed	$ 400	$ 10	3
 Standard Bed	$ 200	$ 2	1

WANT TO ADD BEDDING?

Product	Price	Annual Saving	Reduce CF
 Organic Cotton Bedding	$ 100	$ 2	1
 Standard Bedding	$ 50	$ 1	0.5

YOU HAVE TO HOLD A PARTY, WHICH TABLE DO YOU CHOOSE?

Product	Price	Annual Saving	Reduce CF
 Green Furniture	$ 300	$ 2	1
 Standard Furniture	$ 200	$ 1	0.5

TIME FOR RELAXING, WHICH SOFA DO YOU PICK?

Product	Price	Annual Saving	Reduce CF
 Green Furniture	$ 400	$ 3	1
 Standard Furniture	$ 200	$ 1	0.5

AFTER SEEING EMMA's NEW HOME YOU DECIDE TO REPLACE YOUR UGLY OLD CARPET WITH HEALTHY, ORGANIC AND SUSTAINABLE FLOORING.

Product	Price	Annual Saving	Reduce CF
 Eco-friendly, Green Flooring & Carpet	$ 50	$ 10	1
 Standard Flooring	$ 25	$ 2	0.5

EXPECTING A NEW MEMBER OF THE FAMILY, AND CONVERTING DAD'S DARK DEN INTO A CUDDLY NURSERY?

Product	Price	Annual Saving	Reduce CF
 Healthy paints	$ 50	$ 2	0.5
 Standard paints	$ 25	$ 0	0.2

BED READING TIME, NEED A LIGHT!

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR Floor Lamp	$ 100	$ 2	1
 Standard Lamp	$ 50	$ 1	0.5

YOUR DOOR LEAKS!

Product	Price	Annual Saving	Reduce CF
 Sliding Door Caulk	$ 50	$ 6	1
No, I don't want to insulate...	$ 0	$ 0	0

HEAT WAVE STRIKES!

Product	Price	Annual Saving	Reduce CF
 Ceiling Fan/Light	$ 150	$ 1	3
 Desk Fan	$ 100	$ 0.2	1.5

WANT TO ADD HOME SEALING?

Product	Price	Annual Saving	Reduce CF
 Lap Sealant Caulk Tube	$ 25	$ 2	0.5
No. I don't want to add insulation.	$ 0	$ 0	0

Dining room:

WANT TO CHANGE A LIGHT?

Product	Price	Annual Saving	Reduce CF
 GreenLite Organizer Table Lamp	$ 50	$ 1	1
 Standard Table Lamp	$ 25	$ 0	0.5

HEAT WAVE STRIKES!

Product	Price	Annual Saving	Reduce CF
 Ceiling Fan/Light	$ 150	$ 1	3
 Desk Fan	$ 100	$ 0.2	1.5

WANT TO ADD INSULATION?

Product	Price	Annual Saving	Reduce CF
 Weather seal	$ 100	$ 2	2
No. I don't want to add insulation.	$ 0	$ 0	0

WANT TO LEARN RECYCLE?

Product	Price	Annual Saving	Reduce CF
 Books: Composting & Recycling	$ 25	$ 0	0.5
No. I don't want to add recycle...	$ 0	$ 0	0

WANT TO COMPOST?

Product	Price	Annual Saving	Reduce CF
 Solar Digester	$ 25	$ 0	0.5
No. I don't want to compost...	$ 0	$ 0	0

YOU HAVE TO HOLD A PARTY, WHICH TABLE DO YOU CHOOSE?

Product	Price	Annual Saving	Reduce CF
 Green Furniture	$ 600	$ 6	4
 Standard Furniture	$ 200	$ 1	1.5

HMM...WHICH WILL BE BETTER FOR HEATING WATER?

Product	Price	Annual Saving	Reduce CF
 Tankless hot water heater	$ 200	$ 28	2.5
 Standard water heater	$ 150	$ 4	1.5

WANT TO IMPROVE HOME SEALING?

Product	Price	Annual Saving	Reduce CF
 Eco-Glue™ Earth-Friendly Glue	$ 50	$ 12	1
No. I don't care organic...	$ 0	$ 0	0

YOU HATE BEING THE DISHWASHER! TIME TO PICK A CLEANING KIT!

Product	Price	Annual Saving	Reduce CF
 Eco-Me Home Cleaning Kit	$ 50	$ 0	1
 Standard Home Cleaning Kit	$ 25	$ 0	0.5

YOU JUST BOUGHT TONS OF FROZEN VEGGIES; YOU NEED SOMETHING TO PUT THEM IN.

Product	Price	Annual Saving	Reduce CF
 High-efficiency Refrigerator	$ 300	$ 5	3
 Standard Refrigerator	$ 150	$ 4	1.5

Guest/ Office/ Media/ Storage:

HMM ... THE OLD FAN BROKE! HOW ARE YOU GOING TO EXCHANGE THE AIR?

Product	Price	Annual Saving	Reduce CF
 Dayton 133 CFM Ventilation Fan	$ 50	$ 0	1
 Standard Ventilation Fan	$ 25	$ 0	0.5

REPLACE TABLE LAMP LIGHTS WITH CFLS OR LED BULBS!

Product	Price	Annual Saving	Reduce CF
 Good Earth Table Lamp	$ 50	$ 1	1
 Standard Table Lamp	$ 25	$ 0	0.5

NEED A CHARGER?

Product	Price	Annual Saving	Reduce CF
 Universal Solar Charger	$ 100	$ 12	4
 Standard Charger	$ 50	$ 3	1

LET'S DANCE!

Product	Price	Annual Saving	Reduce CF
 Energy Star 3.0	$ 350	$ 18	4
 Standard Home Theatre	$ 100	$ 2	1

YOU SPEND 10 HOURS EVERYDAY WITH YOUR COMPUTER, PICK UP AN EFFICIENT MONITOR!

Product	Price	Annual Saving	Reduce CF
 GOOD EARTH Monitor/Display	$ 200	$ 5	2
 Standard Desktop	$ 100	$ 2	1

YOUR PRINTER IS DOWN. CHOOSE A NEW ONE!

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR All-in-one	$ 300	$ 12	2.5
 Standard All-in-one	$ 250	$ 3	2

YOUR HAVE HUGE AMOUNT OF PAPER TO READ. YOU NEED A COPIER!

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR Copiers and fax machines	$ 200	$ 2	1
 Standard Copiers and fax machines	$ 150	$ 1	0.5

YOU ARE WROKING AT HOME, WHICH OFFICE TABLE DO YOU CHOOSE?

Product	Price	Annual Saving	Reduce CF
 Green Furniture	$ 800	$ 15	4
 Standard Furniture	$ 200	$ 4	1

TWO WEEKS OF STORM WEATHER. YOU NEED A DEHUMIDIFIER!

Product	Price	Annual Saving	Reduce CF
 ENERGY STAR Dehumidifier	$ 100	$ 20	1
 Standard Dehumidifier	$ 50	$ 2	0.5

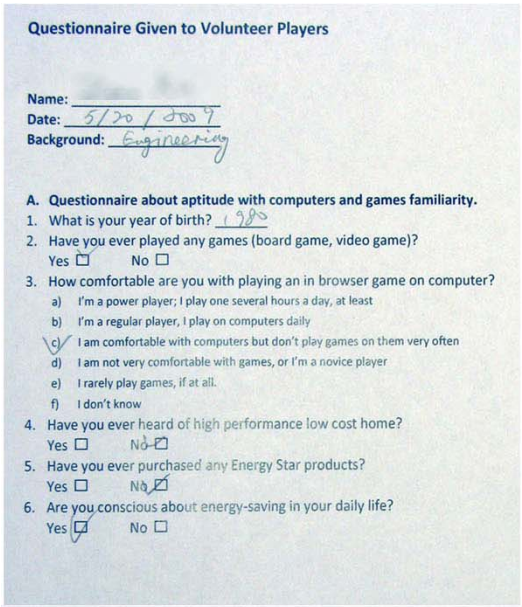
TIME TO BUY A POWER STRIP MONITOR!

Product	Price	Annual Saving	Reduce CF
 Power Strip w/ Monitor	$ 100	$ 18	3
 Power Strip	$ 50	$ 2	1.5

Appendices 2:

User Exercises

User 1:

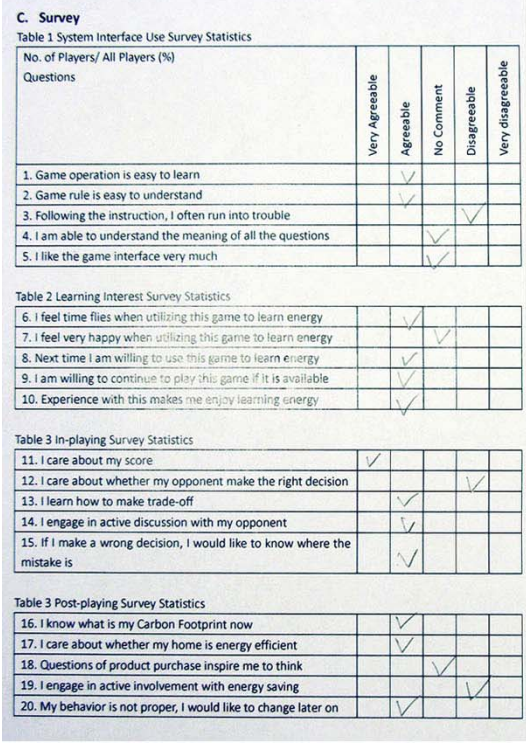


Questionnaire Given to Volunteer Players

Name: [redacted]
Date: 5/20/2009
Background: Engineering

A. Questionnaire about aptitude with computers and games familiarity.

1. What is your year of birth? 1980
2. Have you ever played any games (board game, video game)?
   Yes ☐ No ☐
3. How comfortable are you with playing an in browser game on computer?
   a) I'm a power player; I play one several hours a day, at least
   b) I'm a regular player, I play on computers daily
   c) ✓ I am comfortable with computers but don't play games on them very often
   d) I am not very comfortable with games, or I'm a novice player
   e) I rarely play games, if at all.
   f) I don't know
4. Have you ever heard of high performance low cost home?
   Yes ☐ No ☐
5. Have you ever purchased any Energy Star products?
   Yes ☐ No ☐
6. Are you conscious about energy-saving in your daily life?
   Yes ☐ No ☐



C. Survey

Table 1 System Interface Use Survey Statistics

No. of Players/ All Players (%) Questions	Very Agreeable	Agreeable	No Comment	Disagreeable	Very disagreeable
1. Game operation is easy to learn		✓			
2. Game rule is easy to understand		✓			
3. Following the instruction, I often run into trouble				✓	
4. I am able to understand the meaning of all the questions			✓		
5. I like the game interface very much			✓		

Table 2 Learning Interest Survey Statistics

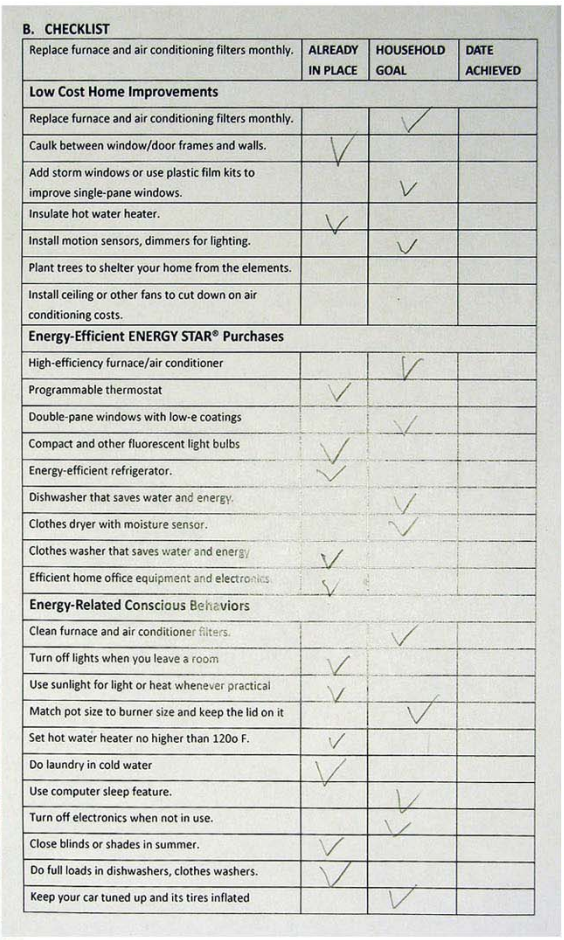
6. I feel time flies when utilizing this game to learn energy		✓			
7. I feel very happy when utilizing this game to learn energy			✓		
8. Next time I am willing to use this game to learn energy		✓			
9. I am willing to continue to play this game if it is available		✓			
10. Experience with this makes me enjoy learning energy		✓			

Table 3 In-playing Survey Statistics

11. I care about my score	✓				
12. I care about whether my opponent make the right decision				✓	
13. I learn how to make trade-off		✓			
14. I engage in active discussion with my opponent		✓			
15. If I make a wrong decision, I would like to know where the mistake is		✓			

Table 3 Post-playing Survey Statistics

16. I know what is my Carbon Footprint now		✓			
17. I care about whether my home is energy efficient		✓			
18. Questions of product purchase inspire me to think			✓		
19. I engage in active involvement with energy saving				✓	
20. My behavior is not proper, I would like to change later on		✓			



B. CHECKLIST

Replace furnace and air conditioning filters monthly.	ALREADY IN PLACE	HOUSEHOLD GOAL	DATE ACHIEVED
Low Cost Home Improvements			
Replace furnace and air conditioning filters monthly.		✓	
Caulk between window/door frames and walls.	✓		
Add storm windows or use plastic film kits to improve single-pane windows.		✓	
Insulate hot water heater.	✓		
Install motion sensors, dimmers for lighting.		✓	
Plant trees to shelter your home from the elements.			
Install ceiling or other fans to cut down on air conditioning costs.			
Energy-Efficient ENERGY STAR® Purchases			
High-efficiency furnace/air conditioner		✓	
Programmable thermostat	✓		
Double-pane windows with low-e coatings		✓	
Compact and other fluorescent light bulbs	✓		
Energy-efficient refrigerator.	✓		
Dishwasher that saves water and energy.		✓	
Clothes dryer with moisture sensor.		✓	
Clothes washer that saves water and energy	✓		
Efficient home office equipment and electronics	✓		
Energy-Related Conscious Behaviors			
Clean furnace and air conditioner filters.		✓	
Turn off lights when you leave a room	✓		
Use sunlight for light or heat whenever practical	✓		
Match pot size to burner size and keep the lid on it		✓	
Set hot water heater no higher than 120o F.	✓		
Do laundry in cold water	✓		
Use computer sleep feature.		✓	
Turn off electronics when not in use.		✓	
Close blinds or shades in summer.	✓		
Do full loads in dishwashers, clothes washers.	✓		
Keep your car tuned up and its tires inflated		✓	

User 2:

Questionnaire Given to Volunteer Players

Name: [redacted]
Date: May 20
Background: Counting

A. Questionnaire about aptitude with computers and games familiarity.

1. What is your year of birth? 1974
2. Have you ever played any games (board game, video game)?
   Yes ☒ No ☐
3. How comfortable are you with playing an in browser game on computer?
   a) I'm a power player; I play one several hours a day, at least
   b) I'm a regular player, I play on computers daily
   c) I am comfortable with computers but don't play games on them very often
   d) I am not very comfortable with games, or I'm a novice player
   e) I rarely play games, if at all.
   f) I don't know
4. Have you ever heard of high performance low cost home?
   Yes ☐ No ☒
5. Have you ever purchased any Energy Star products?
   Yes ☒ No ☐
6. Are you conscious about energy-saving in your daily life?
   Yes ☒ No ☐

B. CHECKLIST

Replace furnace and air conditioning filters monthly.	ALREADY IN PLACE	HOUSEHOLD GOAL	DATE ACHIEVED
Low Cost Home Improvements			
Replace furnace and air conditioning filters monthly.		X	
Caulk between window/door frames and walls.		X	
Add storm windows or use plastic film kits to improve single-pane windows.		X	
Insulate hot water heater.		X	
Install motion sensors, dimmers for lighting.		X	
Plant trees to shelter your home from the elements.	X		
Install ceiling or other fans to cut down on air conditioning costs.	X		
Energy-Efficient ENERGY STAR® Purchases			
High-efficiency furnace/air conditioner		X	
Programmable thermostat		X	
Double-pane windows with low-e coatings		X	
Compact and other fluorescent light bulbs		X	
Energy-efficient refrigerator.		X	
Dishwasher that saves water and energy.	X		
Clothes dryer with moisture sensor.		X	
Clothes washer that saves water and energy	X		
Efficient home office equipment and electronics.		X	
Energy-Related Conscious Behaviors			
Clean furnace and air conditioner filters.		X	
Turn off lights when you leave a room	X		
Use sunlight for light or heat whenever practical		X	
Match pot size to burner size and keep the lid on it		X	
Set hot water heater no higher than 120o F.		X	
Do laundry in cold water		X	
Use computer sleep feature.	X		
Turn off electronics when not in use.		X	
Close blinds or shades in summer.		X	
Do full loads in dishwashers, clothes washers.	X		
Keep your car tuned up and its tires inflated		X	

C. Survey

Table 1 System Interface Use Survey Statistics

No. of Players/ All Players (%) Questions	Very Agreeable	Agreeable	No Comment	Disagreeable	Very disagreeable
1. Game operation is easy to learn		X			
2. Game rule is easy to understand		X			
3. Following the instruction, I often run into trouble				X	
4. I am able to understand the meaning of all the questions		X			
5. I like the game interface very much	X				

Table 2 Learning Interest Survey Statistics

6. I feel time flies when utilizing this game to learn energy	X				
7. I feel very happy when utilizing this game to learn energy	X				
8. Next time I am willing to use this game to learn energy		X			
9. I am willing to continue to play this game if it is available	X				
10. Experience with this makes me enjoy learning energy	X				

Table 3 In-playing Survey Statistics

11. I care about my score	X				
12. I care about whether my opponent make the right decision		X			
13. I learn how to make trade-off	X				
14. I engage in active discussion with my opponent	X				
15. If I make a wrong decision, I would like to know where the mistake is	X				

Table 3 Post-playing Survey Statistics

16. I know what is my Carbon Footprint now	X				
17. I care about whether my home is energy efficient	X				
18. Questions of product purchase inspire me to think		X			
19. I engage in active involvement with energy saving		X			
20. My behavior is not proper, I would like to change later on			X		

User 3:

Questionnaire Given to Volunteer Players

Name: [illegible]
Date: 5/20/2009
Background: Physics

A. Questionnaire about aptitude with computers and games familiarity.

1. What is your year of birth? 1992
2. Have you ever played any games (board game, video game)?
   Yes ☑ No ☐
3. How comfortable are you with playing an in browser game on computer?
   a) I'm a power player; I play one several hours a day, at least
   b) I'm a regular player, I play on computers daily
   c) ✓ I am comfortable with computers but don't play games on them very often
   d) I am not very comfortable with games, or I'm a novice player
   e) I rarely play games, if at all.
   f) I don't know
4. Have you ever heard of high performance low cost home?
   Yes ☐ No ☑
5. Have you ever purchased any Energy Star products?
   Yes ☑ No ☐
6. Are you conscious about energy-saving in your daily life?
   Yes ☑ No ☐

C. Survey

Table 1 System Interface Use Survey Statistics

No. of Players/ All Players (%) Questions	Very Agreeable	Agreeable	No Comment	Disagreeable	Very disagreeable
1. Game operation is easy to learn			✓		
2. Game rule is easy to understand		✓			
3. Following the instruction, I often run into trouble		✓			
4. I am able to understand the meaning of all the questions		✓			
5. I like the game interface very much				✓	

Table 2 Learning Interest Survey Statistics

6. I feel time flies when utilizing this game to learn energy			✓		
7. I feel very happy when utilizing this game to learn energy			✓		
8. Next time I am willing to use this game to learn energy		✓			
9. I am willing to continue to play this game if it is available		✓			
10. Experience with this makes me enjoy learning energy	✓				

Table 3 In-playing Survey Statistics

11. I care about my score		✓			
12. I care about whether my opponent make the right decision				✓	
13. I learn how to make trade-off		✓			
14. I engage in active discussion with my opponent			✓		
15. If I make a wrong decision, I would like to know where the mistake is	✓				

Table 3 Post-playing Survey Statistics

16. I know what is my Carbon Footprint now	✓				
17. I care about whether my home is energy efficient		✓			
18. Questions of product purchase inspire me to think			✓		
19. I engage in active involvement with energy saving	✓				
20. My behavior is not proper, I would like to change later on		✓			

B. CHECKLIST

Replace furnace and air conditioning filters monthly.	ALREADY IN PLACE	HOUSEHOLD GOAL	DATE ACHIEVED
Low Cost Home Improvements			
Replace furnace and air conditioning filters monthly.		✓	
Caulk between window/door frames and walls.		✓	
Add storm windows or use plastic film kits to improve single-pane windows.		✓	
Insulate hot water heater.	✓		
Install motion sensors, dimmers for lighting.		✓	
Plant trees to shelter your home from the elements.	✓		
Install ceiling or other fans to cut down on air conditioning costs.	✓		
Energy-Efficient ENERGY STAR® Purchases			
High-efficiency furnace/air conditioner	✓		
Programmable thermostat		✓	
Double-pane windows with low-e coatings		✓	
Compact and other fluorescent light bulbs	✓		
Energy-efficient refrigerator.	✓		
Dishwasher that saves water and energy.	✓		
Clothes dryer with moisture sensor.		✓	
Clothes washer that saves water and energy	✓		
Efficient home office equipment and electronics.	✓		
Energy-Related Conscious Behaviors			
Clean furnace and air conditioner filters.	✓		
Turn off lights when you leave a room	✓		
Use sunlight for light or heat whenever practical		✓	
Match pot size to burner size and keep the lid on it		✓	
Set hot water heater no higher than 120o F.	✓		
Do laundry in cold water	✓		
Use computer sleep feature.	✓		
Turn off electronics when not in use.	✓		
Close blinds or shades in summer.		✓	
Do full loads in dishwashers, clothes washers.		✓	
Keep your car tuned up and its tires inflated	✓		

User 4:

Questionnaire Given to Volunteer Players

Name: [redacted]
Date: 5/19/2014
Background: BSD

A. Questionnaire about aptitude with computers and games familiarity.

1. What is your year of birth? 1979
2. Have you ever played any games (board game, video game)?
   Yes ☑ No ☐
3. How comfortable are you with playing an in browser game on computer?
   a) I'm a power player; I play one several hours a day, at least
   b) I'm a regular player, I play on computers daily
   c) I am comfortable with computers but don't play games on them very often
   d) I am not very comfortable with games, or I'm a novice player
   e) I rarely play games, if at all.
   f) I don't know
4. Have you ever heard of high performance low cost home?
   Yes ☑ No ☐
5. Have you ever purchased any Energy Star products?
   Yes ☑ No ☐
6. Are you conscious about energy-saving in your daily life?
   Yes ☑ No ☐

B. CHECKLIST

Replace furnace and air conditioning filters monthly.	ALREADY IN PLACE	HOUSEHOLD GOAL	DATE ACHIEVED
Low Cost Home Improvements			
Replace furnace and air conditioning filters monthly.	✓		
Caulk between window/door frames and walls.	✓		
Add storm windows or use plastic film kits to improve single-pane windows.		✓	
Insulate hot water heater.		✓	
Install motion sensors, dimmers for lighting.		✓	
Plant trees to shelter your home from the elements.		✓	
Install ceiling or other fans to cut down on air conditioning costs.	✓		
Energy-Efficient ENERGY STAR® Purchases			
High-efficiency furnace/air conditioner	✓		
Programmable thermostat	✓		
Double-pane windows with low-e coatings		✓	
Compact and other fluorescent light bulbs	✓		
Energy-efficient refrigerator.		✓	
Dishwasher that saves water and energy.	✓		
Clothes dryer with moisture sensor.		✓	
Clothes washer that saves water and energy	✓		
Efficient home office equipment and electronics.	✓		
Energy-Related Conscious Behaviors			
Clean furnace and air conditioner filters.	✓		
Turn off lights when you leave a room	✓		
Use sunlight for light or heat whenever practical	✓		
Match pot size to burner size and keep the lid on it	✓		
Set hot water heater no higher than 120o F.		✓	
Do laundry in cold water		✓	
Use computer sleep feature.	✓		
Turn off electronics when not in use.	✓		
Close blinds or shades in summer.		✓	
Do full loads in dishwashers, clothes washers.		✓	
Keep your car tuned up and its tires inflated		✓	

C. Survey

Table 1 System Interface Use Survey Statistics

No. of Players/ All Players (%) Questions	Very Agreeable	Agreeable	No Comment	Disagreeable	Very disagreeable
1. Game operation is easy to learn	✓				
2. Game rule is easy to understand	✓				
3. Following the instruction, I often run into trouble				✓	
4. I am able to understand the meaning of all the questions		✓			
5. I like the game interface very much			✓		

Table 2 Learning Interest Survey Statistics

6. I feel time flies when utilizing this game to learn energy			✓		
7. I feel very happy when utilizing this game to learn energy		✓			
8. Next time I am willing to use this game to learn energy		✓			
9. I am willing to continue to play this game if it is available		✓			
10. Experience with this makes me enjoy learning energy	✓				

Table 3 In-playing Survey Statistics

11. I care about my score	✓				
12. I care about whether my opponent make the right decision	✓				
13. I learn how to make trade-off	✓				
14. I engage in active discussion with my opponent			✓		
15. If I make a wrong decision, I would like to know where the mistake is				✓	

Table 3 Post-playing Survey Statistics

16. I know what is my Carbon Footprint now		✓			
17. I care about whether my home is energy efficient	✓				
18. Questions of product purchase inspire me to think	✓				
19. I engage in active involvement with energy saving		✓			
20. My behavior is not proper, I would like to change later on			✓		

Appendices 3

Questionnaire Given to Volunteer Players

Name: _____
Date: _____
Background: _____

A. Questionnaire about aptitude with computers and games familiarity.

1. What is your year of birth? _____
2. Have you ever played any games (board game, video game)?
   Yes ☐ No ☐
3. How comfortable are you with playing an in browser game on computer?
   a) I'm a power player; I play one several hours a day, at least
   b) I'm a regular player, I play on computers daily
   c) I am comfortable with computers but don't play games on them very often
   d) I am not very comfortable with games, or I'm a novice player
   e) I rarely play games, if at all.
   f) I don't know
4. Have you ever heard of high performance low cost home?
   Yes ☐ No ☐
5. Have you ever purchased any Energy Star products?
   Yes ☐ No ☐
6. Are you conscious about energy-saving in your daily life?
   Yes ☐ No ☐

B. CHECKLIST[88]

	ALREADY IN PLACE	HOUSEHOLD GOAL	DATE ACHIEVED
Low Cost Home Improvements			
Replace furnace and air conditioning filters monthly.			
Caulk between window/door frames and walls.			
Add storm windows or use plastic film kits to improve single-pane windows.			
Insulate hot water heater.			
Install motion sensors, dimmers for lighting.			
Plant trees to shelter your home from the elements.			
Install ceiling or other fans to cut on air conditioning costs.			
Energy-Efficient ENERGY STAR® Purchases			
High-efficiency furnace/air conditioner			
Programmable thermostat			
Double-pane windows with low-e coatings			
Compact and other fluorescent light bulbs			
Energy-efficient refrigerator.			
Dishwasher that saves water and energy.			
Clothes dryer with moisture sensor.			
Efficient home office equipment and electronics.			
Energy-Related Conscious Behaviors			
Clean furnace and air conditioner filters.			
Turn off lights when you leave a room			
Use sunlight for light or heat whenever practical			
Match pot size to burner size and keep the lid on it			
Set hot water heater no higher than 120o F.			
Do laundry in cold water			
Use computer sleep feature.			
Turn off electronics when not in use.			
Close blinds or shades in summer.			
Do full loads in dishwashers, clothes washers.			
Keep your car tuned up and its tires inflated			

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15. If I make a wrong decision, I would like to know where the mistake is					

Table 4 Post-playing Survey Statistics

16. I know what is my Carbon Footprint now					
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19. I engage in active involvement with energy saving					
20. My behavior is not proper, I would like to change later on					

Bibliography:

1. Beaudin, Jennifer S. (2003). From Personal Experience to Design: Externalizing the Homeowner's Needs Assessment Process. MS Thesis Media Arts and Sciences, Massachusetts Institute of Technology.

2. Duke, R. D. (1974). Gaming, the Futures Language. SAGE Publications, John Wiley and Sons, London/New York.

3. Habraken, N.J. and M.D. Gross. (1998). "Concepts design games." Design Studies 9(3): 150-158.

4. J. Foreman. (2003). "Next-Generation Educational Technology versus the Lecture," EDUCAUSE Review, Vol. 38, No. 4.

5. K. Larson, M. Tapia, and J. Duarte. (2001). "A New Epoch: Automated Design Tools for the Mass Customization of Housing." A+U 366, March.

6. Kalay Y.E.; Jeong Y. (2003). A Collaborative Design Simulation Game. International Journal of Architectural Computing, 1 December 2003, vol. 1, iss. 4, pp. 423-434(12)

7. keri Facer, "Computer Games and Learning: Why Do We Think it's Worth Talking about Computer Games and Learning in the Same Breath?" Nesta FutureLab website.

8. Kurt Squire and Henry Jenkins. (2003). "Harnessing the Power of Games in Education." Insight. Vol. 3.

9. Larson, Kent. (2000). "The Home of the Future." A+U 361, October.

10. Larson, Kent. (2002). Open source building alliance white paper. Cambridge, Massachusetts Institute of Technology.

11. Lawrence, T. (2003). Chassis + Infill: A Consumer-Driven, Open Source Building Approach for Adaptable, Mass Customized Housing. Department of Mechanical Engineering. Cambridge, Massachusetts Institute of Technology.

12. Malone, TW and Lepper, MR. (1987). Making learning fun: a taxonomy of intrinsic motivations for learning, in: RE Snow & MJ Farr (Eds) Aptitude, Learning, and Instruction, III: Cognitive and Affective Process Analysis (pp 223-253). Hillsdale, NJ: Lawrence Erlbaum Associates.

13. Marc Prensky. (2004). Digital-Game Based Learning. New York: McGraw-Hill.

14. Markus M. Ulrich. Simulation/Gaming for Learning about Sustainability and the Environment. Swiss Federal Institute of Environmental Science and Technology (EAWAG/ETH), Duebendorf-Zurich, Switzerland.

15. Matthew Giles Phillips. (2007). Design by Searching: A System for Creating and Evaluating Complex Architectural Assemblies. SMArchS Thesis, Department of Architecture, Massachusetts Institute of Technology.

16. McFarlane, A, Sparrowhawk, A and Heald, Y (2002). Report on the Educational Use of Games. TEEM (Teachers Evaluating Educational Multimedia): www.teem.org.uk

17. McLeish, T.J. (2003). A Platform for Consumer Driven Participative Design of Open (Source) Buildings. M.S. Thesis Media Arts and Sciences, Massachusetts Institute of Technology.

18. Michael Heim. (1993) The Metaphysics of Virtual Reality. Oxford University Press.

19. Mitchell, William J. and McCullough, Malcolm. (1995). Digital Design Media, 2 ed.

20. Negroponte, Nicholas. (1975). Soft Architecture Machines. Cambridge, MA: The MIT Press.

21. Robert Venturi. (1977). Complexity and Contradiction in Architecture, 2nd edition. Harry N. Abrams.

22. Simon, Herbert A. (1996). The Sciences of the Artificial, 3rd edition. Cambridge, MA: The MIT Press.

23. The future of innovation. (2005, March 10). The rise of the creative consumer. The economist. Retrieved September 3, 2006.

24. Thomke, S. & Von Hippel, E., (2007). Customers as Innovators: A new way to create value. Harvard Business Review, April 1, 2002, A7.

254. Torres M. and Macedo, J (2000). Learning Sustainable Development with a New Simulation Game, Simulation & Gaming 2000 31: 119-126.

26. Wei Yan, Geqing Liu. (2007). BIMGame: Integrating Building Information Modeling and Games to Enhance Sustainable Design and Education. Computer Aided Architectural Design in Europe (eCAADe) 2007, Frankford, Germany.